

S O C I A L E C O L O G Y W O R K I N G P A P E R 1 5 1

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# **Economy-wide Material Flow Accounting Introduction and Guide**

**Version 1.0**

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## **Preamble: The SEC MFA guide**

The Institute of Social Ecology (SEC) guide for economy wide material flow accounting (EW-MFA) provides an introduction into accounting principles and practical support for students, statisticians, researchers and all others concerned with material flow accounting. This guide is a revised and modified version of the 2009 draft of the Eurostat MFA compilation guide, which served as a working document in the process of the development of the current Eurostat Guide for EW-MFA.<sup>1</sup> The guidelines have been updated and adapted to fit the needs for a global application and for the reconstruction of historic time series of material flow data. The guide refers to international databases with global coverage and provides suggestions and examples for estimation procedures and coefficients for different world regions and historic time periods. Adaptations have been made in particular for the estimation of grazed biomass and crop residues, for the estimate of sand and gravel consumption in construction activities and for gross ore estimations. Material flow accounting is a dynamic field and methods and data sources are continuously improved. The guidelines should be seen as work in progress and the methods and estimation procedures described in this handbook represent the state of the art in 2014. Methods and estimation procedures can and should be adapted to country specific situations. Further improvements and adaptation of the methods is strongly encouraged.

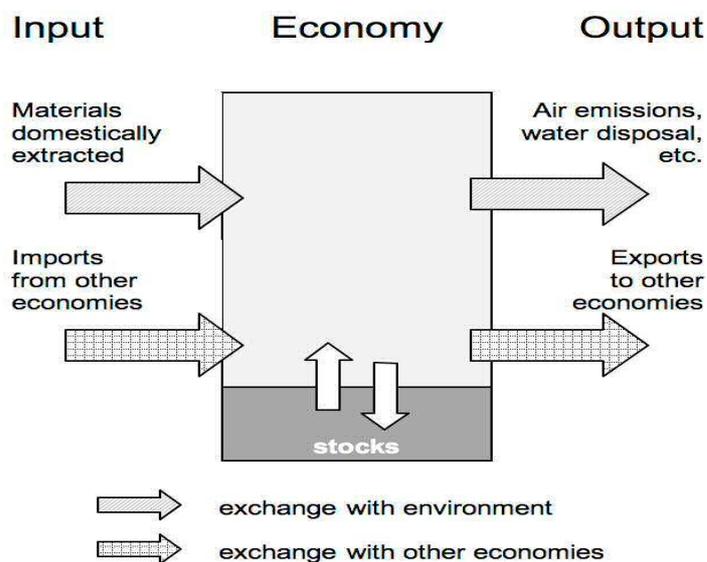
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<sup>1</sup> Economy-wide Material Flow Accounts (EW-MFA), Compilation Guide 2013, 10 September 2013, European Statistical Office. Available at: [http://epp.eurostat.ec.europa.eu/portal/page/portal/environmental\\_accounts/documents/2013\\_EW-MFA\\_Guide\\_10Sep2013.pdf](http://epp.eurostat.ec.europa.eu/portal/page/portal/environmental_accounts/documents/2013_EW-MFA_Guide_10Sep2013.pdf).

## Introduction

In the past years the physical dimension of economic processes, in particular the socio-economic use of materials, was increasingly recognized internationally as a key area for a sustainable development strategy. In 2001 the Gothenburg Council adopted the Sustainable Development Strategy which was revised in 2006 (Council of the European Union 2006). Japanese policy makers already very early focussed on resource use and recycling and Japan was the first country to implement a legal binding policy programme, the 3R action plan, in 2001 (Takiguchi and Takemoto, 2008). The 6<sup>th</sup> environmental action programme (European Parliament and Council 2002) specifies the sustainable use of resources as one of six priority fields for the period 2002 to 2012. A thematic strategy on a sustainable use of resources was published by the European Commission in 2005 (Commission of the European Communities 2005). An OECD council recommendation on material flows and resources productivity in April 2004 fostered the establishment of an OECD work program on this topic by the OECD working group on environmental information and outlook. In 2007, UNEP initiated the foundation of an international expert panel on a sustainable use of resources. Most recently, the European Commission published the flagship initiative on “A Resource Efficient Europe” (2011) and half a year later the Roadmap to a Resource Efficient Europe (2011) with DMC and resource productivity as headline indicators<sup>2</sup>.

**Figure 1: Scope of economy-wide MFA**



<sup>2</sup> see [http://ec.europa.eu/environment/resource\\_efficiency/about/roadmap/index\\_en.htm](http://ec.europa.eu/environment/resource_efficiency/about/roadmap/index_en.htm) and <http://ec.europa.eu/resource-efficient-europe/>

These processes substantially increased the need for economy-wide, reliable and comparable time-series data and indicators for material use. The backbone of an environmental reporting system which provides such information is economy-wide material flow accounting (MFA). Economy-wide material flow accounts are consistent compilations of the overall material inputs into national economies, the changes of material stock within the economic system and the material outputs to other economies or to the environment (Fig. 1).

**Economy-wide MFAs**, for the sake of brevity referred to as MFA in the following document, cover all solid, gaseous, and liquid materials, except for bulk water and air; the unit of measurement is tonnes (i.e. metric tonnes) per year. Similarly to the system of national accounts, material flow accounts serve two major purposes. The detailed accounts provide a rich empirical database for numerous analytical studies. They are also used to compile different extensive and intensive material flow indicators for national economies at various levels of aggregation. Economy-wide MFA thereby is to be seen as a satellite system to the system of national accounts which aims at describing the total scale of socio-economic activities in physical quantities.

The first economy-wide material flow accounts, in the contemporary sense, were published in the early 1990s for Austria (Steurer 1992), Japan (Ministry of the Environment, 1992), and Germany (Schütz and Bringezu 1993). Two publications by the World Resources Institute pioneered the comparative empirical analysis of national economies in material terms and the development of internationally comparable MFA indicators, Adriaanse et al. (1997) and Matthews et al. (2000).

A major step towards **methodological harmonization** was the publication *Economy-wide material flow accounts and derived indicators: A methodological guide* (Eurostat 2001). This guide specified the underlying concept of material flow accounting and the design of material flow indicators. Agreements were based on extensive discussion within the Eurostat MFA task force which met twice in 2000. However, the 2001 guide lacks specific information regarding the compilation of MFAs. The report *Materials use in the EU-15. Indicators and Analysis*, published by Eurostat one year later (Eurostat 2002), presented the first official MFA data set for the EU-15 and provided detailed information on a number of practical aspects of the accounting methods in its technical part. In several meetings between 2004 and 2006, the Eurostat MFA task force continued its efforts on methodological standardisation by developing a material flow classification, MFA standard tables, and detailed procedures on how to compile an economy-wide MFA for European Union member states. European MFA experts developed MFA compilation guidelines which have been revised several steps and different versions of MFA compilation guidelines are available

(Eurostat 2007, 2009c, 2012 and 2013). In July 2011 the European Parliament established the Regulation (EU) No 691/2011, which provides a legal base for the compilation of material flow accounts as a key reporting tool in the European Union's environmental and economic accounts. At the international level, several global datasets are available covering MFA data (Schaffartzik et al., 2014, Giljum et al., 2014, Schandl and West, 2010)<sup>3</sup> and a publication by Fischer-Kowalski and colleagues (2011) summarizes the state of the art of material flow accounting.

Information on the conceptual framework of MFA and how to technically compile the data is spread over several reports and papers. With this guide, we want to provide a concise summary of up to date MFA concepts and methods. Thus, the **purpose** of this guide is two-fold. First, it documents the **conceptual framework and methodological standards** in economy-wide MFA as they have been, for example, adopted by the European Union. Second, it provides **practical step-by-step procedures** for the compilation of economy-wide international material flow accounts.

Researchers and students from various fields who have an academic interest in MFA will find useful information and methodological guidance in this reference manual, as well as practitioners in the statistical office who may use this guide as well, regardless of the specific reporting schema to which they are committed.

The remaining of the manual is organized as follows. The second chapter (**Fundamentals**) summarizes the fundamental definitions and conceptual principles, applied in economy-wide material flow accounting, and introduces the reader to the various partial accounts and the overall structure of the MFA standard tables. The third chapter 3 (**domestic extraction, Table A**) provides step-wise procedures for the accounting of domestic extraction of biomass, minerals and fossil fuels, including the description of data sources, crosschecking opportunities, estimation methods, information on conversions and coefficients. The fourth chapter (**imports and exports, Tables B, C, D, and E**) explains the relevant sources and steps in compiling the physical accounts for imports and exports. The fifth chapter (**domestic processed output: DPO, Table F**) covers the analogous accounting information for outputs to the environment. This touches an area of MFA which is less well developed in methodological terms. The information is based on the currently available conventions but has to be considered as work in progress. Likewise for the sixth chapter (**balancing items and net additions to stock, Table E**), which explains the complex issue of how a consistent

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<sup>3</sup> Data compilations are available at: <http://www.materialflows.net/>, <http://www.uni-klu.ac.at/socec/inhalt/1088.htm> and <http://www.cse.csiro.au/forms/form-mf-start.aspx>

material balance for a national economy is completed. The seventh chapter (**Material flow indicators**) defines and discusses the aggregated extensive and intensive indicators that can be derived from economy-wide material flow accounts and provides some empirical examples.

## Fundamentals

### System boundaries

Economy-wide material flow accounting is conceptually based on a simple systemic model of an economy (referred to as national economy in the following document) as a biophysical and socio-economic system embedded in its socio-economic and biophysical environment. The term embedded indicates that socio-economic systems in general are conceived as materially (and energetically) open systems, i.e. systems that maintain socially organized material (and energy) exchanges with their environment. Such a biophysical understanding of a socio-economic system is commonly referred to as **social or industrial metabolism** (Fischer-Kowalski 1998; Ayres and Simonis 1994).

For the purposes of EW-MFA compilation, the specific socio-economic system under investigation is the national economy into or from which two types of material input or output flows are possible. On the input side, we distinguish between inputs from the natural environment and material imports from other national economies (the rest of the world (ROW)-economy). Likewise, on the output side, we distinguish between outputs into the environment and material exports to other economies.

EW-MFA is consistent with the principles and system boundaries of the system of national accounts (ESA 95, SEEA)<sup>4</sup> and follows the residence principle. It accounts for material flows associated with the activities of all resident units of a national economy regardless of their geographic location. In EW-MFA two types of material flows across system boundaries are relevant:

1. Material flows between the national economy and the natural environment: This consists of the extraction of primary (i.e., raw, crude or virgin) materials from and the discharge of materials to the natural environment (wastes and emissions to air and water);

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<sup>4</sup> <http://unstats.un.org/unsd/envaccounting/seea.asp>

2. Material flows between the national economy and the ROW-economy. This encompasses imports and exports.

Only flows that cross the system boundary on the input-side or on the output-side are counted. Material flows *within* the economy are not represented in economy-wide MFA and balances. This means that the national economy is treated as a black box in MFA and e.g. inter-industry deliveries of products are not described.

#### *Used and unused extraction:*

Inputs from the natural environment are called "**domestic extraction**". This refers to the purposeful extraction or movement of natural materials by humans or human-controlled means of technology (i.e., those involving labour) insofar as they are considered resident units. Not all materials that are deliberately extracted or moved in the extraction process ultimately enter the economy; and not all materials are moved with the intention of using them in the economy. We therefore distinguish between used and unused extraction.

"Used refers to an input for use in any economy, i.e. whether a material acquires the status of a product. [...] Unused flows are materials that are extracted from the environment without the intention of using them, i.e. materials moved at the system boundary of economy-wide MFA on purpose and by means of technology but not for use" (Eurostat 2001: 20). Examples of unused extraction are soil and rock excavated during construction or overburden from mining, the unused parts of fellings in forestry, the unused by-catch in fishery, the unused parts of the straw harvest in agriculture or natural gas flared or vented. The commonly used term "domestic extraction" – abbreviated DE – always refers to "used" extraction if not otherwise specified (some authors also refer to this as "domestic extraction used" with the abbreviation DEU). In some early MFA publications "unused extraction" is also called "hidden flows". This compilation guide does not include unused extraction.

## **Stocks and flows**

The distinction between stocks and flows is another fundamental principle of any material flow system. In general, a **flow** is a variable that measures a **quantity per time period**, whereas a **stock** is a variable that measures a **quantity per point in time**. MFA is a pure flow concept. It measures the flows of material inputs, outputs and stock changes within the national economy in the unit of tonnes (= metric tonnes) per year. This means that in MFA stock changes are accounted for but not the quantity of the socio-economic stock itself.

Although MFA is a flow concept, it is still important to define carefully what is regarded as a material stock of a national economy because additions to stocks and removals from stock are essential parts of the MFA framework. The definition of material stocks is also crucial in identifying which material flows should or should not be accounted for as inputs or outputs. This leads to an alternative definition of the system boundary. Input flows are all material flows that serve as an input to produce or reproduce the socio-economic material stocks measured at the point where they cross the MFA specific system boundary. Output flows are discharges into the environment of the focal socio-economic system. This implies that they are measured at the point where society loses control over the further location and composition of the materials.

In MFA, **three types** of socio-economic material **stocks** are distinguished: artefacts, animal livestock, and humans. **Artefacts** are mainly man-made fixed assets as defined in the national accounts such as infrastructures, buildings, vehicles, and machinery as well as inventories of durable products. Durable goods purchased by households for final consumption are not considered fixed assets in the national accounts but are regarded as materials stocks in economy-wide MFA.

Also the **human population** and **animal livestock** are regarded as socio-economic stocks in national MFA. This means that for a full national material balance not only all food and feed (including non-marketed feed such as grass directly consumed by ruminants on pastures) but also the respiration of humans and animals must be taken into account as material inputs and outputs (most importantly CO<sub>2</sub> emissions).

Theoretically, the calculation of net stock changes should also include the changes in human population and animal livestock. However, experience shows that these stock changes are very small compared to e.g. the stock accumulation through buildings, machinery or consumer durables. In practice, therefore, the changes in human population and animal livestock are often ignored.

As a consequence of this definition of socio-economic stocks, some material stocks are considered natural and not socio-economic despite the fact that they are part of the economic production system. This applies to **agricultural plants and forests**<sup>5</sup>, including cultivated forests, and to **fish stocks** (unless they are cultivated in aquacultures). It is indeed

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<sup>5</sup>According to ESA 95 forests are regarded a socio-economic stock in national accounts; changes in forest stocks are defined as “work in progress”. To allow for consistency between national accounts and EW-MFA it was agreed that net changes in forest stocks should be accounted for as memorandum item in EW-MFA (see section A 1.3 Wood).

not the socio-economic importance of the stock that determines its attribution to the socio-economic system but rather the degree of control that a society exerts over the production and reproduction of the stock.

From a more theoretical point of view, it should be kept in mind that humans colonize – in the sense of exercising sustained and organized control over natural processes – more and more elements of the material world of which they are a part of (Fischer-Kowalski and Weisz 2005). The intensity with which humans colonize different parts of their natural environment is not equally distributed though. More or less intensive colonization technologies may be applied to make use of the various material stocks provided by the natural environment. By and large the attribution of stocks to either the natural or the socio-economic system is intended to follow a gradient of colonisation intensities. In this respect the livestock production system can be considered a more intensively colonized system than the plant and timber production system.

There is another more practical reason why cultivated plants are regarded as natural stocks. Treating plants as parts of the national economy would create the necessity to account for water, CO<sub>2</sub>, and plant nutrients as the primary inputs from the environment. Effectively, this would mean that the system boundary between a national economy and its environment would have to be drawn at the inorganic level (i.e. plant nutrients, CO<sub>2</sub> and water). Statisticians would be forced to convert rather robust and valid data on annual agricultural and timber harvest to comparably weak estimates of the primary inputs needed to produce these plants. Moreover, all differentiation between different types of crops would be lost, as well as the conceptual link to the system of national accounts. It is hard to imagine how such data could possibly be interpreted in a meaningful way, given the limitations of a black box accounting system such as MFA.

There are some areas, where the system boundaries are difficult to define, e.g. where the degree of control over material stocks is varying or may change over time. Cases in point are shifts from uncontrolled to controlled landfills and the increasing importance of fish production through aquaculture as opposed to fish catch in uncontrolled settings. Controlled landfills are considered socio-economic stocks, which means that treatment of these stocks is an activity within the socio-economic system. Any leaking of substances in the soil or water vapour exhausting from organic wastes in particular, should be considered as outputs to nature. In practical terms, these flows are considered small and thus negligible. Aquaculture systems should also be treated as socio-economic stocks. In this case not the fish production but the nutrients and other inputs as well as the outputs in terms of wastes would have to be taken into account. In general, we assume that both inputs and outputs of aquaculture

systems are already accounted for in domestic extraction (DE), domestic processed output (DPO) and trade flows (for definitions see below). Regarding waste flows it has been agreed upon, that only waste going to uncontrolled landfills should be accounted for in MFA.

## **Material balance principle**

As MFA accounts for materials entering and leaving a system, the **conservation of mass principle** applies, which states that matter can neither be created nor destroyed. Although this principle is not universally true (as nuclear reactions are able to transform mass into energy) it is a sufficiently appropriate formulation for the material exchange relations of macro systems.

The mass balance principle can be formulated as:

$$\begin{aligned} \text{input} &= \text{output} + \text{additions to stock} - \text{removals from stock} \\ &= \text{output} + \text{net stock changes} \end{aligned}$$

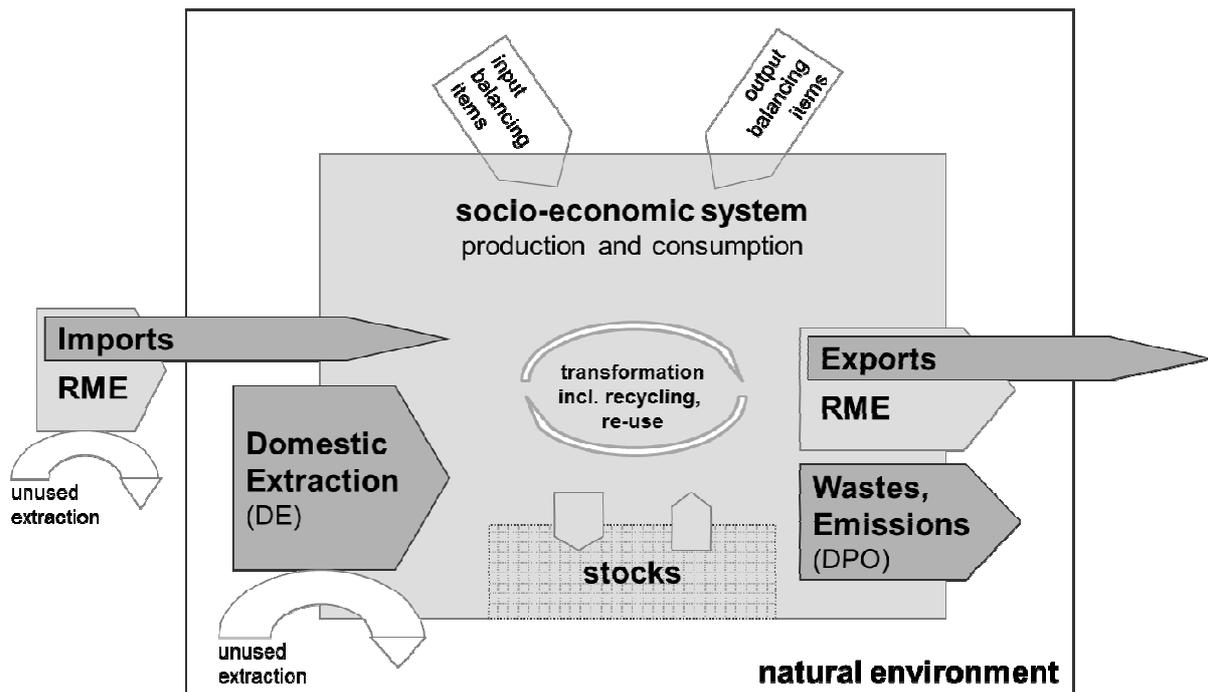
All material inputs into a system over a certain time period equal all outputs over the same period plus the stock increases minus the releases from stock. In principle net stock changes can be positive, indicating net accumulation, or negative, indicating stock depletion.

In MFA, the mass balance principle is used to check the **consistency** of the accounts, see Table H of the EW-MFA tables. It also provides one possibility to estimate the net additions to stock (NAS). It has to be noted, though, that the compilation of a full national material balance is not inevitably the outcome of an economy-wide material flow account. Often partial accounts are compiled, mostly focusing on the input side and trade flows.

## **Typology of flows**

The MFA framework distinguishes between different **material flow categories**. This chapter summarises and completes the description of the general material flow categories and introduces the reader to the relevant terminology. Based on this, we will describe the structure of the economy-wide material flow accounting tables.

**Figure 2: Schematic representation of economy-wide MFA**



Source: Mathews et al. 2000, modified. Legend: DE = domestic extraction; DPO = domestic processed outputs, i.e. wastes, emissions, dissipative uses and losses; RME = raw material equivalents; extr.= extraction

Figure 2 provides a schematic representation of the material flow accounting framework and its main flow categories. All flows that cross the border of the socio-economic system are called direct flows. In Figure 2 these flows are coloured in dark grey.

On the **input-side**, we distinguish between domestic extraction (used; DE), imports, and the input balancing items comprised of those water and air inflows that must be taken into account in order to complete the material balance. On the **output-side**, we distinguish between exports, "domestic processed output" (DPO), and output balancing items. Finally, inputs to and outputs from stocks are considered, resulting in net-changes of stocks. The main material flow categories are defined as follows:

**Domestic Extraction – DE:** The aggregate flow DE covers the annual amount of solid, liquid and gaseous raw materials (except for water and air) extracted from the natural environment to be used as material factor inputs in economic processing. The term "used" refers to acquiring value within the economic system (see Fundamentals > system boundaries). These materials consist of biomass, non-metallic minerals (sometimes also termed construction and industrial minerals), metallic minerals (i.e. gross ores), and fossil energy carriers. Concerning the water content of the raw materials, the convention is to account for all raw materials in fresh weight, with the exception of grass harvest, fodder directly taken up

by ruminants, and timber harvest. These biomass materials are accounted for with a standardised water content of 15%.

**Physical imports and physical exports** (Tables B and C): These aggregates cover all imported or exported commodities in tonnes. Traded commodities comprise of goods at all stages of processing from basic commodities to highly processed products.

**Net Additions to Stock – NAS** (Table F): NAS measures the ‘physical growth of the economy’, i.e. the quantity (weight) of new construction materials accumulating in buildings, infrastructures and of materials incorporated into durable goods with a live time longer than a year such as cars, industrial machinery, and household appliances. Materials are added to the economy’s stock each year (gross additions) and old materials are removed from stock as buildings are demolished and durable goods disposed of (removals). These decommissioned materials, if not recycled, are accounted for in DPO. Net additions to stock are therefore not calculated by balancing additions to stock and stock depletion (as the arrows in Figure 2 would suggest) but as statistical balance between inputs and outputs. Apart from materials going on stocks in the use phase, also products can be put on stocks before being used or traded. This in particular applies for example to fossil fuels or cereals, where stock inventories can be considerable. NAS can also be negative, i.e. net-removals from stocks. Negative NAS have hardly been observed in any industrialized countries, where stock changes mainly refer to increases in infrastructure.

**Domestic processed output – DPO** (Table D): DPO measures the total weight of materials, extracted from the natural environment or imported, that have been *used in the national economy* before flowing to the environment. DPO comprises all waste and emission flows that occur in the processing, manufacturing, use, and final disposal stages of the production-consumption chain. This includes emissions to air, industrial and household wastes deposited in uncontrolled landfills (whereas wastes deposited in controlled landfills are regarded as an addition to the socio-economic stock), material loads in wastewater and materials dispersed into the environment as a result of product use (dissipative flows). Also materials that are deployed to ecosystems intentionally, such as fertilizers should be accounted for as DPO. Recycled material flows are considered flows within the economy (e.g. of metals, paper, glass) and thus are not considered as output (nor input).

**Input and Output balancing items** (Table E): Although bulk water and air flows are excluded from MFA, material transformations during processing may involve water and air exchanges which significantly affect the mass balance. Balancing items are estimations of these flows, which are not part of DE, DPO or NAS, because they are not included in the definition of these flows. Balancing items mostly refer to the oxygen demand of various

combustion processes (both technical and biological ones), water vapour from biological respiration, and from the combustion of fossil fuels containing water and/or other hydrogen compounds. Also flows of considerable economic importance such as nitrogen which is withdrawn from the atmosphere to produce fertilizer in the Haber-Bosch process or groundwater used in the production of beverages are accounted for as balancing items. In the compilation of these flows, only a few quantitatively important processes are taken into account and the flows are estimated using generalized stoichiometric equations.

Having defined these material flow categories, we now can write a national material balance equation in MFA terms:

$$\mathbf{DE + Imports + Input Balancing Items = Exports + DPO + Output Balancing Items + NAS}$$

Apart from these direct flows, further flows can be considered in a broader MFA view. These are: unused extraction associated to direct extraction activities, and upstream material use associated with imports and exports (Eurostat 2001). The latter are usually termed raw material equivalents (RME) of imports and exports. Both flows do not enter the focal socio-economic system but the first, unused extraction remains within the natural system, and the second, RME remains in foreign economies. **Unused extraction** comprises materials that are moved or extracted from the environment without the intention of using them in economic processing. This includes, for example, overburden or unused crop residues (e.g. straw that is burned on field or ploughed into the soil). Unused extraction can be associated with the domestic or foreign extraction of raw materials when the latter is attributable to the production of imported goods. Per definition, materials extracted from the environment are always raw materials. In contrast, imported and exported materials are always products which have already undergone a more or less intensive transformation process before entering or leaving the focal economy. Goods are traded in various stages of processing and the upstream material requirements of imports and exports comprise both used extraction (= raw materials) and unused extraction, together they are referred to as indirect flows. To denote the upstream requirements of used extraction associated with imports or exports the term "**raw material equivalents**" (RME) was coined (Eurostat 2001, Weisz et al. 2004).

Both the present version of the EW-MFA tables and this compilation guide cover the direct flows only, RME and unused extraction are not included. In the case of RME, methods are still under fast development and results (Wiedmann et al. 2013, Wood et al. 2014) are changing significantly depending on the methods used (Schaffartzik et al. 2014). In the case

of unused extraction, data availability is poor and no sufficiently standardised methods have been developed so far.

## **Residence principle**

Like other environmental accounting systems (e.g. air emissions accounts (Eurostat 2009a) MFA follows the residence principle in order to ensure consistency with national accounts. Accordingly, EW-MFAs account for all material flows associated with transactions attributed to so called resident units. In the system of national accounts (ESA 95), resident units are defined as those units whose center of economic interest is located on the national economic territory. A *center of economic interest* is given if the unit is engaged in significant economic activities on the economic territory for a year or more or if it holds ownership of land or buildings on the economic territory. The national *economic territory* encompasses the geographic territory without extraterritorial enclaves and including territorial enclaves as well as air space, territorial waters, deposits over which country has rights, etc.

For the most part, the sources of statistical data employed in MFA compilation are consistent with the residence principle. In some cases, however, data adjustments are required. In particular, this applies to fuel consumed in international transport (water, air, and road). According to the residence principle, fuel that is consumed by resident units abroad (e.g. bunkering of aviation fuel by domestic airlines on ROW-economic territory) has to be accounted for in EW-MFA, while vice versa fuel provided to non-resident units domestically has to be excluded. These flows, which can be of considerable size in some countries, are usually not captured by production or trade statistics and have to be estimated. This handbook provides some suggestions on how to estimate these flows, but the information required for these estimates are difficult to obtain for most countries. In practical terms many EW-MFAs still ignore these adaptations. Other areas, where standard statistical sources provide data not fully consistent with the residence principle are tourism and activities in extraterritorial enclaves (such as embassies or consulates). However, the related flows are of a comparatively small size in most cases and statistical data or standardized estimation procedures are hardly available. For these reasons, deviations from the residence principle other than for fuel use are currently not considered in EW-MFA. The adjustments that are required in order to ensure consistency with the residence principle are discussed in greater detail in the section dealing with trade flows.

## **Data sources and quality of the accounts**

Economy-wide materials flow accounts are meta-compilations of data from various official statistics, most of which are regularly provided and updated by national statistical offices. DE is mainly based on data from agricultural, forestry, fishery production, mining (including geological surveys), and energy statistics. DPO is mainly based on emission inventories (including NAMEA of Eurostat) and waste statistics. Import and export data are taken from foreign trade statistics.

Basically, three types of data sources are useful for compiling MFAs. Data provided by the national statistical offices of the country for which the MFA is compiled, international databases (such as those from Eurostat or different UN bodies such as the FAO or IEA, Minerals statistics offered by different geological services such as the USGS or BGS, etc.) and third, data from scientific reports, case studies, and other non-periodical data compilations. Additionally, "educated guesses" by experts may occasionally turn out to be the only means to complete the accounts.

National databases usually have the most reliable data for individual countries because they dispose of the best primary sources and knowledge on national structures and individual characteristics. However, international data sources can provide high quality data which have the advantage of being standardized across countries and thus provide a good basis for cross country comparisons. Often it is necessary to combine national and international data sources in order to close data gaps or for cross checking. In this guide we refer mainly to international databases.

One particular important quality criterion for MFA is its consistency. This includes ensuring that the following general requirements are met.

(1) Only those data must be included which comply with the system boundary definition of MFA.

(2) All data are measured in the same unit of tonnes (i.e. metric tonnes). If data are reported in units other than tonnes they must be converted using appropriate coefficients.

(3) The compilation must be free of double counts. This means that each relevant flow is accounted for only once.

(4) The compilation must be comprehensive. Often there are relevant material flows for which statistical sources provide no or no appropriate data. The compilation of an MFA therefore also involves estimated missing data. As such estimations are a common source of

incomparability, we particularly emphasise the description of possible estimation methods, here. Whereas these estimation methods should provide some guidance as to how to complete data gaps, they are not intended to represent the one solution that works best. Different and possibly more accurate estimation methods may be applied based on national data and national expertise.

(5) It must be ensured that the data are of sufficient quality. This is probably the most difficult task. Judging the quality of statistical and other data requires profound knowledge and sufficient experience in the respective fields. Moreover, the specific nature of the problems typically varies across statistical data sources, countries, and points in time. For these reasons it is hardly possible to provide standardised methods to judge the quality of all data which are relevant for MFA.

The following chapters describe the most common and partly standardized methods based on the guidelines developed for Eurostat (Eurostat 2012) but adapted to better fit a global rather than a European perspective that we suggest for the evaluation of some of the most common and quantitatively most severe data quality problems.

The future value of economy-wide material flow accounting will depend largely on its internal consistency, its international comparability, and its potential to reflect a large variety of real world processes. These are at times conflicting goals.

## **The MFA tables**

Together with this manual, we provide a set of different tables that help compiling economy wide Material Flow accounts. These tables are designed to facilitate data organisation, they represent a structuring of material flows and thus are an important tool in the process of MFA compilation. Six tables (A through F) and annexes (0 through 6) form a file in spreadsheet format into which the collected MFA data can be entered according to the type of aggregate to which they belong. These tables and especially the annexes provide valuable information on the individual items to be included in an MFA, including their assigned codes in different systems of notation. The MFA Tables have a hierarchical structure and differentiate between four levels of detail.

Data on **domestic extraction** (DE) of biomass, metal ores, non-metallic minerals, and of fossil energy carriers must be entered into **Table A**. The individual items which make up each of these kinds of domestic extraction are listed under the respective heading. DE of biomass, for example, consists of primary crops (A. 1.1), of used crop residues, fodder crops

and grazed biomass (A.1.2), wood (A.1.3) and of the biomass extracted through fish capture (A.1.4) and hunting and gathering (A.1.5). For reasons of consistency, all tables are organized in the same way and along the same number of items.

Tables B and C are designed for the organisation of data on **trade flows (imports and exports)**. In **Table B** (imports) and **Table C** (exports) data on total trade flows are requested. All trade data is organised into similar categories as the data on domestic extraction, the major difference being that the items traded comprise not only primary but also processed material. The latter may consist of either biomass, metal ores and concentrates, non-metallic minerals, fossil energy carriers, or waste imported for final treatment or disposal. Products which cannot be clearly identified as belonging to one of these four categories should be included under “other products”. The procedure for determining where a given trade flow should be entered is described in annexes of the MFA tables for different trade classification systems (CPA, SITC and HSCN).

Data on discharges into the environment are organised in **Table D** as **domestic processed output** and may consist in emissions to air (D.1.) or water (D.3.), in landfilled waste (D.2.) or in discharges that result from the dissipative use of products (D.4.) as would be the case in the application of fertilizer, for example. Additionally, data on dissipative losses (D.5.) are entered into this table.

Finally, **balancing items** are represented in **Table E**. These data are organised according to whether they comprise those gases required on the input side (E.1.) to balance an output which is already accounted for or gases which must be considered on the output side (E.2.) to balance a given input.

All of the data collected and organised in Tables A through E can then be aggregated permitting for the derivation of **indicators** in **Table F**. Based on known volumes of domestic extraction (F.1.), imports (F.2.), and exports (F.3.), the direct material input (F.4.), domestic material consumption (F.5.), and the physical trade balance (F.6.) can be calculated. By additionally considering domestic processed output (F.7.) and balancing items (Table E), net additions to stock (F.8.) may be determined.

In order to facilitate the proper organisation of data from different sources within one harmonious system, a set of annexes in spreadsheet format provides information on the correspondence between the various statistical codes used to designate relevant items. In **Annex 0** the **structure of Tables A to F** is shown in correspondence with the structure of the MFA tables. **Annex 1 and b** show the **Classification of Products by Activity** (CPA 2002 and 2008) in its correspondence to domestic extraction and trade flows. Domestic

extraction of biomass may also be labelled with **FAO** codes; the according correspondence is provided in **Annex 2**. In **Annex 3a and b** the trade flows (Tables B and C) are presented in correspondence with the **Standard International Trade Classification** (SITC) rev. 1, rev. 3 and rev. 4 codes as well as CN and HS classification. Annex 4a and b provide information on the correspondence between MFA classification and FAOSTAT classification of trade with agricultural and forestry products. Annex 5 is a correspondence table between MFA categories and the fossil energy carrier classification according to IEA. Annex 6 contains a correspondence table for mineral and fossil materials as listed in the United Nations Industrial Commodities Production Statistics and material flow groups.

## Table A: Domestic extraction

### Biomass

**Table 1: Domestic extraction of biomass**

1 digit	2 digit	3 digit
A.1	Biomass	
	A.1.1	Primary crops
		A.1.1.1 Cereals
		A.1.1.2 Roots, tubers
		A.1.1.3 Sugar crops
		A.1.1.4 Pulses
		A.1.1.5 Nuts
		A.1.1.6 Oil bearing crops
		A.1.1.7 Vegetables
		A.1.1.8 Fruits
		A.1.1.9 Fibres
		A.1.1.10 Other crops (Spices, Stimulant crops, Tobacco, Rubber and other crops)
	A.1.2	Crop residues (used)
		A.1.2.1 Straw
		A.1.2.2 Other crop residues (sugar and fodder beet leaves, other)
	A.1.3	Fodder crops and grazed biomass
		A.1.3.1 Fodder crops (incl. harvest from grassland)
		A.1.3.2 Grazed biomass
	A.1.4	Wood
		A.1.4.1 Timber (Industrial roundwood)
		A.1.4.2 Wood fuel and other extraction
	A.1.5	Fish capture and other aquatic animals and plants
		A.1.5.1 Fish capture
		A.1.5.2 All other aquatic animals and plants
	A.1.6	Hunting and gathering

### Introduction

Biomass comprises organic non-fossil material of biological origin. According to MFA conventions, domestic extraction (DE) of biomass includes all biomass of vegetable origin

extracted by humans and their livestock, fish capture, and the biomass of hunted animals. Biomass of livestock and livestock products (e.g. milk, meat, eggs, hides) are not accounted for as domestic extraction (see below).

Biomass accounts for 30% of total global DE (Krausmann et al. 2009). Values of per capita biomass harvest average at 3 t and range between 0.5 and 20 t. Typically, the share of primary crops of total harvest amounts to 35%, crop residues 20%, fodder crops and grazed biomass 32%, and wood 10%. Fishing and hunting and gathering are of minor quantitative importance in most cases. The actual quantitative and qualitative structure of biomass harvest may vary significantly depending on the regional characteristics of the land use system. In general, DE of biomass is highest in countries with low population densities or high livestock numbers per capita.

DE of biomass includes a number of raw materials which differ significantly in terms of their technical, economical, and environmental properties, which are reflected in the 2 to 4 digit structure of the MFA Table (see Table A.1.).

Economic value: The economic value of biomass ranges from very low (less than 10€/t, e.g., crop residues) to medium high (e.g., spices, stimulants, fish catch); the vast majority of extracted biomass is comprised of bulk raw materials with low value (10-100€/t, e.g., cereals, roundwood).

Socio-economic use: Biomass provides raw materials for the food system, but also energy carriers and industrial raw material for a wide range of processes and products (e.g., fibres, chemical compounds, construction material, industrial raw material).

Environment: The extraction of biomass materials can be related to specific land use and land cover types (cropland, grassland, and woodland) and environmental pressures (deforestation, soil erosion, ground water pollution, biodiversity loss, over-fishing).

## **Data sources**

Statistical reporting of biomass extraction has a long tradition. Most fractions of biomass harvest are reported by national statistical offices (or national offices concerned with agriculture and forestry) in their series of agricultural, forestry, and fishery statistics. Additional information useful for biomass accounts may be provided by national food, feed, and wood balances. The accounting frameworks are well established and show a high degree of international standardisation and accuracy. Both national and international data sources generally cover the harvest of all types of primary crops (1.1) and wood (1.4), and biomass extraction by fishing and hunting activities (1.5 and 1.6). In some cases crop residues (1.2.1) and harvested fodder crops and biomass harvested from grassland (1.2.2.1)

are reported in statistical accounts as well, but grazed biomass (1.2.2.2) is usually not estimated by official statistics. For these items, which usually are of considerable quantitative significance, this guide provides standard estimation procedures.

The most consistent international source of data on biomass extraction is the statistical database provided by the United Nations Food and Agricultural Organization. The FAO database covers a huge range of data concerning agriculture, forestry, and fishery, and the food system on the level of nation states in time series since 1961. The structure of the EW-MFA tables is compatible with the data provided by the FAO (see Annex 2 for a detailed correspondence table).

In discussing the aggregation and estimation procedures, the guide follows the two and three digit level of the MFA tables.

## **Conventions**

**Terminology and classification:** The terminology and classification of biomass items and aggregates used in this guide by and large follow the terminology used by the FAO and may differ from the terminology used in national statistics.

**Moisture content:** A characteristic feature of all types of biomass is its considerable moisture content (mc), which may account for more than 95% in the case of fresh living plant biomass. However, the moisture content is very variable across plant parts and species and vegetation periods. In many cases, biomass is harvested at low moisture content (e.g., cereals) or dried during the harvesting process (e.g., hay making). In accordance with agricultural statistics, biomass is accounted for at its “as is weight” at the time of harvest. Few crops may be harvested at different water contents (fresh weight (80-95% mc) or air dry (15% mc)); in these cases, moisture content has to be standardised according to MFA conventions. This applies only for the categories A.1.2.2.1 fodder crops, A.1.2.2.2 grazed biomass, and A. 1.4. wood.

**Primary harvest and crop-residues:** In many cases, primary harvest (i.e. the used fraction accounted for in MFA) is only a fraction of total plant biomass. However, the remaining crop-residue or a certain fraction of it may be subject to further socio-economic use and is accounted for in MFA. The most prominent example for this is (cereal)straw, which may either be used as bedding material for livestock, feed stuff, for energy generation or as raw material used for other purposes (crop residues which are ploughed into the field or burnt are not accounted for as DE). This also applies to wood harvest, where fellings and removals are distinguished.

**Livestock:** According to MFA system boundaries and conventions, livestock is considered an element of the physical compartment of the socio-economic system. Consequently, all direct biomass uptake by livestock is accounted for as domestic extraction, whereas livestock and livestock products are considered secondary products and not accounted for as domestic extraction. Exceptions are hunted animals and fish capture, which are considered an extraction from the natural environment and, therefore, are accounted for as DE. Biomass uptake by livestock consists of market feed (cereals, food processing residues, etc.), fodder crops (fodder beets, leguminous fodder crops, etc.), crop residues used as feed (straw, beet leaves, etc.), and grazed biomass. Domestic extraction of market feed is included in the extraction of primary crops (item A.1.1), crop residues used for feed in item A.1.2.1 and fodder crops, grassland harvest and grazed biomass in item A.1.2.2.

## **Data Compilation**

### **A 1.1 Crops**

Harvest of primary crops is comprised of primary harvest of all crops from arable land and permanent cultures. This includes major staple foods from crop- and garden land such as cereals, roots and tubers, pulses, vegetables as well as commercial feed crops, industrial crops and all fruits and nuts from permanent cultures. The FAO's crop production database distinguishes roughly 160 different types of primary crops (including fruits and nuts from permanent cultures). In most countries, the numbers of primary crops will be much smaller; for European countries, it typically ranges between 30 and 50.

Data on the extraction of primary crops are provided in good quality by national and international statistical sources and can be used directly for MFA compilation without further processing. With respect to aggregation of the harvest of individual crops to the 3 digit level of the standard tables, we follow the classification scheme suggested by the FAO which is also compatible with CPC classification. The table in the Annex 2 of the EW-MFA tables lists all common crop types according to the 3 digit level of the standard tables (A.1.1.1 to A.1.1.10). Crops not identified in this list, but reported by national statistics should be classified with regard to the 3 digit level or, if this is not possible, subsumed under A.1.1.10 (other crops) (e.g. flowers or nursery products).

### **A 1.2 Crop residues**

In most cases, primary crop harvest is only a fraction of total plant biomass of the respective cultivar. The residual biomass, such as straw, leaves, stover etc., often is subject to further economic use. A large fraction of crop residues is used as bedding material in livestock husbandry but crop residues may also be used as feed, for energy production or as industrial

raw material. The used fraction of crop residues is accounted for as DE. In many countries this is a considerable flow which may account for 10-20% of total biomass DE. Residues which are left in the field and ploughed into the soil or burned in the field are not accounted for as DE.

MFA accounts distinguish between two types of crop-residues:

A.1.2.1 Straw of cereals: all harvested straw of cereals including maize

A.1.2.2 All other crop-residues: For most European countries this will refer to tops and leaves of sugar beets and only occasionally to residues from other crops (e.g. sugar cane, etc.).

In some cases, all or some harvested crop-residues are accounted for in national agricultural statistics. However, FAOSTAT nor national agricultural statistics in most countries report any data on harvested crop-residues. In case national statistics provide data on the used fraction of crop-residues, these can directly be used for MFA compilation without further processing. For most countries, however, crop-residues and the assigned fraction will have to be estimated:

Step 1: Identification of crops which provide residues for further socio-economic use. In most cases this will include all types of cereals (A.1.1.1), sugar crops (A.1.1.3) and oil bearing crops (A.1.1.6), only in exceptional cases will other crops have to be considered.

Step 2: Estimation of available crop residues via harvest factors

The procedure to estimate the amount of crop residues available is based on assumptions on the relation between primary harvest and residues of specific crops. In agronomics, different measures for this relation are used: the most prominent are the harvest index, which denotes the share of primary crop harvest of total aboveground plant biomass, and the grain to straw ratio. This relation is typical for each cultivar, however, subject to changes over time as plant breeding aims specifically at increasing the harvest index of cultivars. Based on this, we can calculate a harvest factor, which allows for the extrapolation of total residue biomass from primary crop harvest (equation (1)). Typical harvest factors for crops in different world regions, which can be used in absence of national information, are provided in Table 2a.

**Note:** The harvest factors in Table 2a refer to dry matter of both crop and crop residue. MFA reports crops and crop residues with the moisture content at harvest (as is weight). In most cases the moisture content of crop and crop residues is equal (e.g. cereal straw and grain both have a mc of roughly 16%). In this case the factors in Table 2a can be applied without modification; if the moisture content between crop and crop residue differs, however, corresponding adjustments have to be made.

(1) Available crop residues [t (as is weight)] = primary crop harvest [t (as is weight)] \* harvest factor

**Table 2: Standard values for harvest factors (a) and recovery rates (b) for common crop residues.**

	E. Asia	E. Europe	Latin America	N. Africa W. Asia	N. America Oceania	S. and C. Asia	Subsaharan Africa	W. Europe
a) Harvest factors. Crop residue [g dry matter (DM) per year] = primary crop harvest [g DM/yr] * harvest factor.								
Wheat, other cereals	1.5	1.5	1.5	1.5	1.2	1.7	2.3	1.0
Rice, Paddy	1.0	1.2	1.2	1.2	1.2	1.5	1.5	1.2
Maize	3.0	1.9	3.0	3.0	1.2	3.5	3.5	1.2
Millet	3.0	1.9	3.0	3.0	1.2	3.5	3.5	1.2
Sorghum	3.0	1.9	3.0	3.0	1.2	3.5	3.5	1.2
Roots and Tubers	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Cassava	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Sugar Cane	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Sugar Beets	0.7	0.5	0.7	0.7	0.5	0.7	0.7	0.5
Pulses	0.4	1.0	0.4	0.4	1.0	0.4	0.4	1.0
Soybeans	1.2	1.5	1.5	1.5	1.2	1.5	1.5	1.2
Groundnuts in Shell	1.2	1.2	1.5	1.5	1.2	1.5	1.5	1.2
Oil Palm Fruit	1.5	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Castor Beans	0.4	1.0	0.4	0.4	1.0	0.4	0.4	1.0
Rapeseed, oil crops	2.3	1.9	2.3	2.3	1.9	2.3	2.3	1.9
Permanent crops	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
b) Recovery rates: Used crop residues [g DM] = available residues [g DM] * recovery rate.								
Cereals	0.8	0.75	0.8	0.8	0.7	0.9	0.9	0.7
Roots and Tubers	0.75	0.25	0.75	0.75	0	0.75	0.75	0
Sugar Cane	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Sugar Beets	0.75	0.25	0.75	0.75	0	0.75	0.75	0
Sugar Crops nes	0.8	0.3	0.8	0.8	0	0.8	0.8	0
Beans, Dry	0.5	0.5	0.5	0.5	0	0.5	0.5	0
Other pulses	0.8	0.75	0.8	0.8	0.7	0.9	0.9	0.7
Other oil crops	0.8	0.75	0.8	0.8	0.7	0.9	0.9	0.7
Oil Palm Fruit	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Sunflower Seed	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Rape seed	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7

Source: based on data provided in Krausmann et al. 2013 and Wirsenius 2000.

### Step 3: Estimation of fraction of used residues

In most cases, only a certain fraction of the totally available crop-residue will be harvested and subject to further use. The actual fraction of residues used (recovery rate) can be estimated based on expert knowledge or specific studies. In cases in which no reliable information on the country-specific share of used residues is available, recovery rates provided in Table 2b can be applied, but It has to be noted that these are only rough

approximations and actual rates may vary considerably across countries and over time. The amount of used crop residues can be calculated using equation (2).

(2) Used crop-residues [t (as is weight)] = available crop-residues [t (as is weight)] \* recovery rate

### **A.1.3 Fodder crops (incl. biomass harvested from grassland) and grazed biomass**

This category subsumes different types of roughage including fodder crops, biomass harvested from natural or improved grassland (meadows) and biomass directly grazed by livestock. Coverage of these large flows in statistics is usually poor. The most important types of fodder crops may be reported in harvest statistics (e.g. maize for silage, leguminous fodder crops, hay) and for some countries national feed balances exist from which data on biomass harvested from grassland and grazed biomass can be derived. In case no reliable data for both fodder crops (A 1.3.1) and grazed biomass (A 1.3.2) exist, formula (5) (see section A 1.3.2 below) can be used to estimate the total amount of biomass subsumed under A 1.3. In this case, the calculated total requirement for roughage is assumed to be equal to the total amount of harvested fodder crops and grazed biomass (A 1.3).

#### **A.1.3.1 Fodder crops (incl. harvest from grassland)**

This category includes all types of fodder crops including maize for silage, grass type and leguminous fodder crops (clover, alfalfa etc.), fodder beets and also mown grass harvested from meadows for silage or hay production. All commercial feed crops such as barley, maize, soy bean etc. which may also be used for food production or as industrial raw material are not included in this category. Fodder crops are typically reported by national agricultural statistics. In some cases, standardisation of moisture content is required:

Step 1: Fodder crops which require a standardisation of moisture content must be identified: All grass type fodder crops and biomass harvested from meadows (FAO codes 638-643 and 857-859, see Annex 2 of the EW-MFA tables) can be harvested and used either fresh (i.e. with a high moisture content; for immediate feeding or silage production) or at air dry weight (hay). According to MFA conventions, these crops are accounted for at air dry weight, i.e., at a standardised moisture content of 15%. In case no information on the moisture content of the reported data on fodder crops is available, a rough check can be made by looking at yields per area unit: The yield of grass type fodder crops at air dry weight [t/ha/yr] is typically in the range of 2-3 times the yield of cereals (e.g., wheat or barley). Fresh weight yields are significantly higher and are 5-15 times the yield of cereals.

Step 2: The weight of fodder crops which are reported in fresh weight (i.e., at a moisture content of 80%) has to be reduced to a moisture content of 15% by applying equation (3) and then (4):

$$(3) \text{ Factor}_{\text{mc}} = (1 - \text{mc}_{\text{fresh}}) / (1 - \text{mc}_{\text{air dry}}) = 0,2 / 0,85 = 0,235$$

$$(4) \text{ Air dry weight (at 15\% mc)} = \text{fresh weight (at 80\% mc)} * \text{Factor}_{\text{mc}}$$

#### A.1.3.2 Grazed biomass

According to MFA conventions, biomass grazed by livestock is accounted for in material flow accounts. This type of biomass extraction is not reported in standard agricultural statistics. In some cases, information on grazing is available from national feed balances or can be obtained from local agricultural experts. These data can be used for MFA accounts, eventually quantities given in other units (e.g. dry weight or digestible energy) have to be converted to air dry weight (15% mc) with the support of information from feed composition tables or expert knowledge or by using equation (4).

Different methods are available to estimate the amount of biomass grazed by livestock: One method uses the number of animals, which is well documented in agricultural statistics, and calculates an average feed or roughage demand by using information on daily feed intake per head. This approach is described in detail as method A in this manual. The second approach uses data on the amount of animal products (meat, milk, eggs) produced and information on the ratio of feed required to produce one unit of output (feed conversion rate). These methods have been used in material flow accounts and allow for a rough estimate of biomass uptake by grazing.

##### Method A: Demand-driven feed balance to identify grazing gap.

Information on livestock numbers are typically well reported in national and international agricultural statistics. Based on information on roughage requirements of ruminants and other grazing animals and the number of livestock, the demand for grazed biomass can be estimated. Daily biomass intake by grazing depends on the age and live weight of the animal, animal productivity (e.g., weight gain, milk yield), and the feeding system (e.g., feed composition) and therefore may vary considerably within one species even within a country depending on the prevalent livestock production systems. The procedure described here is a simplified version of a feed balance model used in estimates of global biomass harvest (see Krausmann et al. 2008 and Krausmann et al. 2013, see this literature for more information and detailed feed balances). Table 3 provides information of average roughage uptake by

livestock species in different production systems (3a) and averages for different world regions over time (3b). The values refer to air dry weight (i.e. at a moisture content of 15%) and already take into consideration that the share of market feed and crop residues in feed ratios ranges between 5 and 50% (dry matter basis, average across all species). The coefficients in Table 3 can be used to calculate total roughage requirement (equation (5)).

**Table 3a: Typical roughage intake by grazing animals**

	<b>Annual intake Traditional livestock system [t/head and year]</b>	<b>Annual intake Industrial livestock system [t/head and year]</b>
Cattle (and buffalo)	1.5	5.5
Sheep and goats	0.43	0.64
Horses	3.0	4.3
Mules and asses	1.8	2.6

Values represent annual intake of air dry biomass (15% mc) in t / head and year. Sources: The values are typical for industrialised livestock production systems and derived from national feed balances and literature (Wirsenius 2000; Hohenecker 1981; Wheeler et al. 1981; BMVEL 2001).

**Table 4b: Estimate of annual intake of forage by cattle and buffalo in 1960, 1990 and 2005**

t/head/y	<b>South &amp; Central Asia</b>	<b>East Europe</b>	<b>North Africa &amp; West Asia</b>	<b>North America &amp; Oceania</b>	<b>West Europe</b>	<b>Sub- Saharan Africa</b>	<b>Latin America &amp; Caribbean</b>	<b>East Asia</b>	<b>World</b>
1960	1.6	2.3	2.3	3.4	3.3	2.4	3.1	2.0	2.5
1990	1.5	2.9	2.6	5.1	4.5	2.4	3.4	2.6	2.9
2005	1.6	2.8	2.5	5.6	5.1	2.3	3.8	3.8	3.3

Forage intake includes grazed biomass, hay and forage crops. Values are given in in t (at 15%mc) /head /y. Intake of market feed and crop residues is already discounted for. Source: derived from Krausmann et al. 2013.

(5) Roughage requirement = livestock [number] \* annual feed intake [t per head and year]

Roughage uptake may be covered from grass type fodder crops, hay or silage or from grazing. To estimate biomass uptake by grazing, total roughage uptake has to be reduced by the amount of available fodder crops and biomass harvest from grassland (item A.1.3.1) (equation (6)).

(6) Demand for grazed biomass = roughage requirement [t at 15% mc] – fodder crops [t at 15% mc].

### Method B: Extrapolation from animal production (feed conversion efficiency):

National and international agricultural statistics also report data on primary animal products such as meat and milk. From this information and appropriate feed conversion coefficients (feed demand per unit of product) the demand for feed and subsequently also grazed biomass can be extrapolated. It is important that the applied feed conversion coefficients take the demographic structure of the herd into account. This means, for example, that not only the feed consumed by the cows which produce milk is taken into account, but also the feed required for the calves, heifers and steers required to maintain the herd of cows. Data on domestic production of animal products needs to be corrected for trade with live animals: an imported steer which is slaughtered after import will be recorded in production statistics, but the feed required to produce the steer was not consumed in the importing but in the exporting country. Therefore, the slaughter weight of imports and exports of live animals has to be subtracted or added, respectively, from domestic meat production. Another source of underestimation of this method concerns livestock services other than meat and milk. In particular in low income countries, a significant share of the total livestock may be used primarily to provide draught power (e.g. horses, oxen, buffaloes) or wool (sheep). The feed demand to provide these services will not be accounted for with this method and needs to be estimated separately (e.g. using method A).

Method B has been applied in the MFA accounts of the CSIRO and UNEP Asia-Pacific Material Flows database (CSIRO 2010) using coefficients derived from Wirsenius 2000. We here present a simplified version of this method: In a first step the amount of feed energy (digestible energy) required to produce each type of primary animal product (carcass in slaughter weight or whole milk by animal species) is calculated using conversion coefficients given in Table 4a (equation (7)). The share of grazed biomass in total feed is calculated using equation (8) using information on the region specific share of roughage in feed (Table 4b). The amount of grazed biomass is converted from digestible energy into mass at 15% moisture content using an average value of digestible energy per unit of roughage of 10.4 MJ/kg DM (Wirsenius 2003, Table B.5) and the moisture content value of 0.85 (equation (9)). In case information on the harvest of forage crops (grasses, legumes, corn for silage) is available and reported under A1.3.1, these have to be subtracted from total roughage demand.

(7) Feed requirement for product  $i$  [GJ] = kg product  $i$  [t] \* feed conversion coefficient product  $i$  [KJ/kg]

(8) Roughage demand product  $i$  [GJ] = Total feed requirement  $i$  [GJ] \* share of roughage [%]

(9) Grazed biomass product  $i$  [t at 15% mc] = roughage demand product  $i$  [GJ] / 10.4 [MJ / kg dry matter] / 0.85 - fodder crops [t at 15% mc]

**Table 5a: Feed conversion coefficients**

		South & Central Asia	East Europe	North Africa & West Asia	North America & Oceania	West Europe	Sub-Saharan Africa	Latin America & Caribb.	East Asia
Cattle meat	MJ/kg carcass	499.0	160.0	151.0	132.0	126.0	373.0	264.0	313.0
Cow milk	MJ/kg milk	13.8	10.0	14.3	6.9	7.4	29.1	13.2	11.0
Sheep and goat meat	MJ/kg carcass	998.0	320.0	570.0	264.0	252.0	746.0	528.0	626.0
Sheep and goat milk	MJ/kg milk	27.6	19.9	28.6	13.8	14.8	58.2	26.4	21.9

Feed energy requirement per unit of animal product (MJ digestible energy per kg of product) by world region. Meat refers to carcass weight (slaughter weight), milk to whole, fresh milk. Based on Table 3.9 in Wirsenius 2000.

**Table 6b: Share of roughage in total feed energy supply by world region.**

% of digestible energy	South & Central Asia	East Europe	North Africa & W. Asia	North America & Oceania	West Europe	Sub-Saharan Africa	Latin America & Carrib.	East Asia
Milk cattle	65%	80%	64%	39%	43%	69%	77%	73%
Beef cattle	67%	79%	64%	60%	58%	69%	77%	69%
Sheep and goats	100%	100%	100%	80%	80%	100%	100%	100%

Roughage includes forage crops such as grasses, legumes, corn for silage and grazed biomass. Values in % of total digestible energy. Based on figure 3.28 in Wirsenius 2000 (p. 139), weighted by digestible energy content (table B5 in Wirsenius 2003).

Note: Both methods are strongly simplified versions of full scale feed balances. Results obtained with method A and B for a specific country can differ considerably. Reasons for inconsistency may lie in primary data (inconsistencies between livestock numbers and animal production), simplified assumptions on feed requirements, feed composition and energy content of feed stuff and also differences in terms of comprehensiveness (e.g. method B focusses on meat and milk and ignores other services such as draught power). Also limitations in the application of the provided region specific coefficients to individual countries and their temporal variability can cause inconsistencies between the two methods. Both methods have their specific shortcomings and the described procedures are strong simplifications of feed balances and provide only rough estimates of grazed biomass. More detailed methods which take national data, information of feeding systems and the full range of animal species and animal products into account are presented in Wirsenius 2000 and 2003, Krausmann et al. 2013 and Herrero 2013.

Cross check: Supply estimate via grazed area and information on area yield.

In many countries, land use statistics provides data on the extent of grazing land (often differentiated by quality or intensity) in their agricultural or land use statistics. Based on information on the extent of pastures and typical biomass yield per unit of area, the potentially available biomass for grazing can be calculated, assuming an optimum utilization of pasture resources. Country or region specific area yields of pastures and rangelands can be estimated based on expert knowledge and literature data. Table 5 provides information on typical grazing yields for different quality types of pastures in Central Europe (based on data for Austria). These data serve only as an example as pasture yields vary largely according to climate, soil conditions and management (irrigation, fertilization). To apply this crosscheck, country specific information is indispensable. Grazing potential can be calculated using equation (10).

$$(10) \text{ Grazing potential [t at 15\% mc]} = \text{pasture area [ha]} * \text{pasture yield [t at 15\% mc / ha]}$$

**Table 5: Typical area yield of permanent pastures**

	Yield range [t at 15%mc / ha]	Average yield [t at 15%mc / ha]
Rough grazing, alpine pasture	<1	0,5
Extensive pasture	1-5	2,5
Improved pasture	5-10	7,0

Source: The values are derived from data for Austrian grassland systems given in Buchgraber et al. (1994) and can be assumed typical for Central Europe.

The calculated demand for grazed biomass should be lower or equal to the calculated potential supply of grazable biomass. If this is not the case, two aspects should be considered, which may, after expert consultation, lead to an adaptation of the estimates:

- a) the yield factors have been estimated too low
- b) the daily intake factors of livestock have been assumed too high.

Other reasons may be an exceptionally high share of market feed and feed concentrate in feed ratios, overgrazing of pasture resources or significant grazing on areas other than those reported as pasture in land use statistics (woodlands, waste lands etc.).

If no revisions are plausible or possible, the lower of the two estimates should be considered.

### A.1.4 Wood

This category comprises of timber or industrial roundwood (A.1.4.1) and fuel wood (A.1.4.2). It includes wood harvest from forests and also from short rotation plantations or wood from agricultural land.

Extraction of wood is reported in forestry statistics which usually differentiate between coniferous and non-coniferous wood. Wood from short rotation plantations may also be recorded in agricultural statistics, because short rotation forests are considered cropland in many countries. National wood balances, if available, often provide more comprehensive datasets, because they also include wood harvested from non-forested land.

Wood is usually reported in terms of volume rather than weight. Units used are stacked (or piled) cubic meters and solid cubic meters (scm). One stacked cubic meter is considered equal 0.70 solid cubic meters. For MFA accounts, volume measures have to be converted into weight measures using standard conversion factors given in Table 6.

**Table 6: Standard factors to convert quantities given in volume (scm) into weight (at 15% mc) for coniferous and non-coniferous wood.**

	Density [t DM / scm]*	Density [t at 15% mc / scm]
Coniferous	0,44	0,52
Non-coniferous	0,58	0,68
EU25 average (80% coniferous)	0,47	0,55

\*These factors refer to t DM per scm green volume. Source: Based on factors used in IPCC greenhouse gas inventories (Penman et al. 2003).

Fellings vs. removals, bark:

Forestry statistics, especially forest inventories, sometimes distinguish between fellings and removals. MFA considers only the biomass removed from forests for further socio-economic use, i.e. wood removals. All biomass not removed (branches, root-stock, etc.), i.e. fellings minus removals, is not accounted for in MFA. This differentiation has to be considered.

Special care must be taken concerning the issue of bark, which accounts for approximately 10% of stem wood weight. Wood removals are usually reported in scm under bark (i.e. without bark), although wood is removed including bark and a significant fraction of the bark is subject to further socio-economic use (e.g., energy production). In order to correct wood removals reported under bark for bark, we use an extension factor derived from typical values for the bark fraction of stem wood (equation (11):

$$(11) \text{ wood removals incl. bark [t at 15\% mc]} = \text{wood removals under bark [t at 15\% mc]} * 1.1$$

### **A.1.5 Fish capture and other aquatic animals/plants**

Fish capture and extraction of other aquatic animals and plants is reported in national fishery statistics and by FAO fishery statistics (FISHSTAT; <http://www.fao.org/fi/default.asp>). Fish and seafood production from aquaculture is not considered domestic extraction but a secondary product of the livestock sector (see section fundamentals). Therefore, only fish capture (including recreational fishing) and other animals and plants extracted from unmanaged fresh and seawater systems should be reported under item 1.5 in Table A of the EW-MFA tables. In accordance with the residence principle, all landings of national vessels should be included, regardless of the geographic location of landings.

### **A.1.6 Hunting and gathering**

This type of extraction is quantitatively of minor significance and is only accounted for if data are available in national statistics. A conversion from pieces or other physical units into tonnes might be necessary. The 2013 version of the Eurostat MFA compilation guide provides a long list of average weight of hunted animal species (see Eurostat 2013).

## **Specific issues related to DE of biomass**

**Biomass production from subsistence agriculture and home gardening:** According to MFA system boundaries, biomass harvest from subsistence agriculture and home gardening is regarded as domestic extraction of biomass. In industrialized countries, these flows usually are of minor economic and physical significance and usually not included in agricultural statistics. Currently, for European countries, no reliable data and estimation procedures to quantify these flows exist and they are not considered in MFA accounts for practical reasons. In developing countries, though, this category can be of significant size. Estimation procedures might have to be developed.

**Biomass waste from management of parks, infrastructure areas, gardens etc.:** A significant amount of biomass is generated as a by-product of management of home gardens, infrastructure areas, public parks, and sports facilities etc. A certain fraction of this biomass flow, which comprises mown grass, woody biomass, residues from pruning and foliage etc., may be subject to further socio-economic use, e.g. for energy generation or the production of compost or it may appear in waste statistics. According to MFA system boundaries, these fractions are regarded as domestic extraction of biomass (domestic processed output, respectively). However, due to lack of reliable data and estimation

procedures they are currently not accounted for. Recently, this biomass flow has received increasing attention in the context of strategies for sustainable resource use and might be included at a later stage of MFA method development.

**Biomass harvest from set-aside agricultural land:** An increasing amount of agricultural land in the European Union is set-aside. In many cases, this land, however, does not remain uncultivated but is used for the production of renewable resources, such as oil crops or short rotation forests etc. Usually, the biomass from these areas will be considered in national agricultural statistics, in some cases it might be recorded in separate statistical accounts or sources. In any case, it has to be accounted for as domestic extraction and subsumed under the respective item (e.g. under A.1.1.6 oil bearing crops or A.1.4.2 wood fuel).

## Metal ores and non-metallic minerals

**Table 7: Domestic extraction of metal ores**

1 digit	2 digit	3 digit
A.2	Metal ores (gross ores)	
	A.2.1	Iron ores
		A 2.1 Iron ores – gross ore M2.1 Iron ores – metal content
	A.2.2	Non-ferrous metal ores
		A.2.2.1 Copper ores - gross ore M.2.2.1 Copper ores - metal content
		A.2.2.2 Nickel ores - gross ore M.2.2.2 Nickel ores - metal content
		A.2.2.3 Lead ores - gross ore M.2.2.3 Lead ores - metal content
		A.2.2.4 Zinc ores - gross ore M.2.2.4 Zinc ores - metal content
		A.2.2.5 Tin ores - gross ore M.2.2.5 Tin ores - metal content
		A.2.2.6 Gold, silver, platinum and other precious metal ores - gross ore M.2.2.6 Gold, silver, platinum and other precious metal ores - metal content
		A.2.2.7 Bauxite and other aluminium ores - gross ore M.2.2.7 Bauxite and other aluminium ores - metal content
		A.2.2.8 Uranium and thorium ores - gross ore M.2.2.8 Uranium and thorium ores - metal content
		A.2.2.9 Other metal ores - gross ore M.2.2.9 Other metal ores - metal content

**Table 8: Domestic extraction of non-metallic minerals.**

1 digit	2 digit	3 digit
A.3 Non-metallic minerals		
	A.3.1	Ornamental or building stone
	A.3.2	Limestone, gypsum, chalk, and dolomite
	A.3.3	Slate
	A.3.4	Gravel and sand
	A.3.5	Clays and kaolin
	A.3.6	Chemical and fertilizer minerals
	A.3.7	Salt
	A.3.8	Other mining and quarrying products n.e.c.
	A.3.9	Excavated soil, only if used (e.g. for construction work)

## Introduction

Metal ores and non-metallic minerals are the two major groups of minerals that are distinguished at the 1 digit level of the MFA classification. All minerals together accounted for about 51% of the global DE in 2005 (Krausmann et al. 2009), to which metal ores contribute a share of around 17%. Still, a separate representation of metals at the 1 digit level is justified due to their outstanding strategic importance for the industrial metabolism and their comparatively high economic value.

It should be noted that the classification of minerals presented in Tables A.2 and A.3 of the EW-MFA tables does not explicitly distinguish between non-metallic industrial minerals and construction minerals, a distinction that has been applied widely in material flow studies in particular in early years. The reason is that this distinction never was unambiguously and properly defined, as the same mineral often can be used for both industrial and construction purposes. Additionally, construction materials also go through some industrial processing. For a rough indication of the magnitude of minerals mainly destined for the use in the construction sector, the sum of A.3.1, A.3.2, A 3.4, A 3.5 and A 3.9 can be taken. At the detailed level of data compilation, as described below, a more accurate distinction is also possible.

It is important to keep in mind that the category “domestic extraction of minerals” does not include the extraction of gases from the atmosphere for industrial purposes, such as the extraction of nitrogen in the Haber-Bosch process. These flows, if quantitatively important, are accounted for as balancing items (see the chapter on table G).

Per capita minerals extraction in Europe averaged at 8.1 t and ranged typically between 4 and 24 t in 2005. Non-metallic minerals used in the construction industry by far dominate domestic extraction of minerals (e.g. 94% for the EU-15 in 2000). The extraction of industrial minerals and metal ores varies greatly across countries, depending on the availability of exploitable mineral deposits. Only a few large countries like Russia or Australia mine a broad spectrum of ores and industrial minerals, most countries only mine a few of the listed materials.

DE of minerals includes a number of raw materials which differ significantly in terms of their chemical, technical, economic and environmental properties:

**Economic value:** The economic value of minerals ranges from very low (less than 10€/t, e.g. sand and gravel) to very high (e.g., precious metal ores and diamonds); the vast majority of extracted minerals comprises of bulk raw materials with low value (< 100€/t, e.g., sand, mixed gravel, crushed stone).

**Socio-economic use:** Minerals provide raw materials for constructing buildings and infrastructures, materials that enter a wide range of industrial processes and final products (e.g., inorganic chemicals, ceramics, salt for food), and metal ores for also a wide range of uses (e.g. constructions, vehicles, machinery, electrical appliances).

**Environment:** The extraction of mineral materials can be associated with a number of environmental pressures depending on the kind of mineral and the location and type of mining and quarrying activities (ecosystems destruction, sealing of land, toxic waste emissions). A large fraction of these minerals is accumulated in societal stocks of buildings, infrastructures and durable goods; at the end of their lifetime they turn into wastes and are then a potential source for recycling and reuse of fractions of the disposed good. Any recycling and reuse flows are considered to be a flow within the socio-economic system and do not cross the system boundary between the societal system and nature.

## **Data sources**

Statistical reporting of minerals extraction has a long tradition with regards to statistics of the mining industries. On the national level, these commonly report with high reliability on industrial minerals and metal ores, and should be taken as the primary data source. However, mining statistics often do not include (total) numbers for bulk minerals like sand and gravel or crushed stones. Additional information useful for getting comprehensive data on domestic extraction of minerals may be provided by industrial associations (e.g. for the gravel and sand industry or natural stones industry). These may provide figures covering the complete field of activities involved in minerals extraction, for example also small scale enterprises not considered by other statistics. In case statistics of industrial associations or

related data sources are used, it should be ensured that these report continuously on the same items. In some cases, however, data for minerals for construction will have to be estimated (see below).

Apart from national mining statistics, useful data for metallic and industrial minerals may also be obtained from international mining statistics which are mainly:

- European Mineral Statistics, a product of the World Mineral Statistics, published annually by the British Geological Survey (BGS)  
<http://www.bgs.ac.uk/mineralsuk/statistics/wms.cfc?method=searchWMS>
- Minerals Yearbook (Volume III: Area Reports: International), by the U.S. Geological Survey (USGS) <http://minerals.usgs.gov/minerals/pubs/country/index.html#pubs>
- United Nations Industrial Commodity Production Statistics  
[http://unstats.un.org/unsd/industry/ics\\_intro.asp](http://unstats.un.org/unsd/industry/ics_intro.asp)
- Eurostat statistics on the production of manufactured goods (PRODCOM)  
<http://epp.eurostat.ec.europa.eu/portal/page/portal/prodcom/data/database>

The statistics compiled by the **BGS** represent, so far as this is possible, the official data for the countries concerned. BGS reports production as well as imports and exports of a wide range of mineral commodities (including fossil energy carriers). In the case of metals, production data of different steps in metal processing can be selected (mine production, smelter, refining – only mine production is considered an extraction from the natural system, see below), each expressed in terms of metal content. Data are reported for all countries in the world and can be downloaded for free for the years 1980 onwards. The years prior to 1980 are available in pdf files. BGS archives even provide data (in pdf form) from the 1910s onwards.

The **USGS** provides comparable data on the country level along with detailed information on the mineral industry within the studied country, in particular about the structure of the mineral industry in terms of commodity, major operating companies and major equity owners, location of main facilities, and annual capacity. This often provides important detailed information, especially for the metal contents and coupled mining of ores. Time coverage of the data accessible via the internet is usually from 1990 to 2006, but only for most recent years (from 2000 on) in a format that directly allows for data processing (earlier publications are available in PDF format only). USGS archives even contain data tables (pdf) that go back to the 1930s.

For longer time series, the **United Nations Industrial Commodity Production Statistics** provide a valuable source of information (from 1950 onward). The UN, however, publishes

updates roughly one or two years later than the USGS or BGS. For overlapping long time periods up to the most recent year, compatibility between the different databases has to be ensured by analysing and eventually adjusting the different datasets.

**Eurostat** provides the **statistics on the production of manufactured goods (PRODCOM)**. It covers data for the 27 European Union member states and a number of additional countries according to the European PRODCOM system, which is largely identical with the CPA classification system. Production data are available for more than 1000 products in physical and monetary units. However, the completeness of the data varies considerably across countries and years.

**Conventions**

**Terminology and classification:** Mining statistics do not use the same terminology or classification internationally. UN statistics use the ISIC Rev.2-based commodity codes, Eurostat uses PRODCOM and CPA codes respectively, and the BGS and USGS do not refer to standard statistical codes at all. Therefore some caution is required when working with more than one data base to avoid either incomprehensive or double accounting. The terminology and classification of mineral items and aggregates used in this guide by and large follow the terminology used in the CPA.

**System boundaries:** Minerals mining involves the mobilisation of huge amounts of materials. For the compilation of comparable data sets and indicators it is instrumental that the same system boundary is applied. Table 9 gives an overview of the terminology used in MFA with regard to the different flows involved in the extraction of metals.

**Table 9: Different system boundaries in metal mining**

Description of the material	Common terminology	MFA terminology
Materials removed to get access to metal reserve	overburden, interburden	unused extraction
the metal containing material	run of mine, gross ore, crude ore	used extraction
the pure metal	net ore or metal content	metal component of used extraction, not specifically reported in the MFA in the indicators, but reported in the MFA tables as metal content

Accounting for domestic used extraction of minerals always refers to the run-of-mine production. Run-of-mine production means that the total amount of extracted crude mineral

that is submitted to the first processing step is accounted for. Material extracted but not used as an input for subsequent processing is termed unused domestic extraction and is not accounted for. Unused extraction may, for example, include overburden removed and deposited or interburden removed and filled. Databases on mineral production often also include production from further metal processing such as production of smelters or refineries. In MFA only the extraction from the natural system, i.e. mine production in gross ore, is considered as domestic extraction.

**Please note!** Table A.2 of the MFA tables requests that the amount of extracted metals is reported in gross ore (i.e. run-of-mine). Additionally metal content should be reported in the corresponding memorandum items. Although EW-MFA accounts for gross ore, both values are important for crosschecking and for further analysis of the MFA data. But only the run-of-mine value is used to calculate Domestic Extraction and aggregated indicators!

MFA convention requires the inclusion of metals as “**run-of-mine production**”. Mining statistics may report the run-of-mine production, the mass of a concentrate, or the metal content of the gross ore. In the latter two cases, the run-of-mine production has to be derived by calculating the mass of gross ore based on the concentrate or metal content by using ore grades. A proposal for the respective accounting procedure is explained below. The run-of-mine concept concerns metals in particular, but principally holds true for all minerals. For minerals other than metallic ores, it may generally be assumed that the difference between run-of-mine production and reported production is not relevant.

The **ore grade** specifies the metal content of a specific gross ore. This information is required to estimate the mass of gross ore from metal content. Ore grades are variable across ores, mines, and time; an overview of ore grades of different metals (metal content in % of gross ore) in European countries is provided in Table 11. For calculation purposes, ore grades in decimal form should be used (% divided by 100). **Please note!** Statistical sources sometimes report the mass of metal concentrate rather than metal content. Concentrates have a higher metal content than gross ores, but the metal content can vary considerably depending on the nature and composition of the concentrates; typical ore grades of concentrates are provided in the sections dealing with the specific metals.

**Coupled production:** Coupled production refers to ores that contain more than one metal of economic value. For example, lead is often associated with zinc, or tin is often associated with copper in the same deposit. While it is comparatively straight forward to collect data for the mine production of specific metals, coupled production hampers the unambiguous classification of gross ores according to MFA categories. The identification and adequate treatment of coupled production is aggravated by the circumstance that the composition of specific ores may differ between deposits within one national economy. For example, at site

A, an ore containing copper, lead, and zinc may be mined, while at site B, lead and zinc are mined together with gold. In most cases it will not be possible or too time-consuming to quantify the portion of each metal mined in a given form of coupled production. Therefore, in the compilation of material flow accounts, it is advisable to determine which form of mining is dominant for each metal, i.e. that type of ore from which the major part of the metal in question is mined. In case this type of information is not available from the national statistical unit responsible for mining, it can be obtained from the USGS country reports. Holding the dominant form of mining true for all mining of a particular metal is, of course, a simplification, but usually unavoidable due to data constraints.

**Estimations:** Metals are mostly reported in metal content and have to be converted to gross ores by using ore grades as already mentioned above. Additionally, coupled production has to be considered and the gross ore has to be allocated according to a standardized procedure. Bulk minerals for construction are often under-represented in statistics. In these cases it is necessary to estimate the actual amounts of material that has been extracted. This refers mainly to sand and gravel, limestone, and clays for construction. Respective estimation procedures are described in detail in the section concerned with the specific material group.

**Moisture content:** Minerals have specific moisture content that is usually not subject to high variability. Therefore data for the extraction of minerals are simply taken as they are reported.

## Data compilation A.2 metal ores

### Run-of-mine estimation under consideration of coupled production

Run-of-mine or gross ore can be calculated on the basis of data on metal extraction (in tonnes) and the country specific average ore grade. If coupled production for a specific metal can be excluded (that is, only a single metal is extracted from the given ore), equation (12) holds true:

$$(12) \text{ gross ore [t]} = \frac{\text{metal content [t]}}{\text{ore grade}}$$

If more than one metal is extracted from the same gross ore, care must be taken to ensure that the same run-of-mine is not accounted for more than once. In the case that coupled production has been identified for two or more metals, the following calculation procedure can be applied.

*Step 1: Calculation of the total gross ore:* The amount of gross ore required to provide the reported amounts of metals is calculated according to equation (13):

$$(13) \text{ gm}_{\text{tot}} [\text{t}] = \text{m}_{\text{tot}} [\text{t}] / \text{og}_{\text{tot}} [\%]$$

$\text{gm}_{\text{tot}}$  = mass of total gross ore which contains metals  $\text{m}_1$  to  $\text{m}_n$

$\text{m}_{\text{tot}}$  = sum of metals  $\text{m}_1$  to  $\text{m}_n$  contained in the gross ore

The sum of all metal content  $\text{m}_1$  to  $\text{m}_n$  (in tonnes) extracted in coupled production corresponds to the total amount of metal contained in the gross ore in question. The data can be obtained from mining statistics or specific allocation studies.

$\text{og}_{\text{tot}}$  = sum of ore grades ( $\text{og}_1$  to  $\text{og}_n$ )

The sum of all ore grades (in %)  $\text{og}_1$  to  $\text{og}_n$  contained within the same ore corresponds to the total ore grade  $\text{og}_{\text{tot}}$ . The respective ore grades can be obtained from statistics or literature.

*Step 2: Allocation of gross ore to metals from coupled production:* The total amount of gross ore must be attributed to the metals mined in coupled production. This can be done in an aliquot way, based on the fraction of the total ore grade which the respective metal represents. For example, for metal  $\text{m}_1$ , the attributable fraction of total gross ore ( $\text{gm}_1$ ) should be calculated using equation (14):

$$(14) \text{ gm}_1 [\%] = \text{og}_1 / (\text{og}_1 + \text{og}_2 + \dots + \text{og}_n) [\%]$$

Because  $\text{gm}_1$  is the fraction of the total gross ore attributable to the extraction of metal  $\text{m}_1$ , the amount of gross ore associated with the extraction of this metal can be obtained by multiplying  $\text{gm}_1$  with the total gross ore (equation (15)):

$$(15) \text{ gm}_1 [\text{t}] = \text{gm}_{\text{tot}} [\text{t}] * \text{gm}_1 [\%]$$

In the MFA tables, the values for metal content and gross ore (both in tonnes) are reported separately (see section conventions).

The following example illustrates the calculation procedure. Table 10 represents the metal output of a hypothetical economy. Since the data is provided in terms of metal content, it is necessary to calculate the associated gross ore.

**Table 10: Coupled production, Metal output of hypothetical economy**

<b>Metal</b>	<b>Mine Output, Metal Content [t]</b>	<b>Ore Grade</b>	<b>Coupled Production with:</b>
Copper	10 000	0.01	Tin
Iron	300 000	0.5	no coupled production
Lead	30 000	0.08	Zinc
Zinc	150 000	0.05	Lead
Tin	500	0.0002	Copper

In the example given in Table 10 iron is the only metal which is not mined in coupled production (single metal ore). Copper occurs together in one deposit with tin, and lead occurs together with zinc, so that the procedure for coupled production calculation must be followed.

a) Calculation of iron gross ore

$$\text{iron gross ore [t]} = \frac{300\,000 \text{ t}}{0.5} = 600\,000 \text{ t}$$

b) Calculation of Coupled Production Ores

$$\text{copper and tin gross ore [t]} = \frac{10\,000 \text{ t} + 500 \text{ t}}{0.01 + 0.0002} \approx 1\,029\,412 \text{ t}$$

Of this result, 98% ( $=0.01/(0.01+0.0002)$ ) are allocated to copper and the remaining 2% are allocated to tin.

$$\text{lead and zinc gross ore [t]} = \frac{30\,000 \text{ t} + 150\,000 \text{ t}}{0.08 + 0.05} \approx 1\,384\,615 \text{ t}$$

Of this result, 62% ( $=0.08/(0.08+0.05)$ ) are allocated to lead and 38% are allocated to zinc.

Following these steps, the following gross ore results are obtained:

<b>Metal</b>	<b>Mine Output, Gross Ore [t]</b>
Copper	1 009 227
Iron	600 000
Lead	852 071
Zinc	532 544
Tin	20 185

Table 11 provides country-specific ore grades and occurrences of coupled production in Europe. Coupled production is listed for the dominant ore which accounts for the majority of extraction of a specific metal in a country. This information is based on data from international statistical sources. More precise information both on ore grades and coupled production may be available from national statistical sources and should be given preference over the data provided here.

**Table 11: A selection of country-specific ore grades and occurrences of coupled production according to international statistical sources for European countries**

	<b>Metal</b>	<b>Ore Grade [%]</b>	<b>Coupled Production</b>
<b>Austria</b>	W – Tungsten	0.27 to 0.31	–
	Fe – Iron	32	with Mn (total gross ore reported under iron ore)
	Mn – Manganese	0.8	with Fe (total gross ore reported under iron ore)
<b>Bulgaria</b>	Cu – Copper	0.45	with Au, Ag
	Ag – Silver	0.001	with Au, Cu
	Au – Gold	0.0004	with Ag, Cu
	Pb – Lead	7	with Zn
	Zn – Zinc	7	with Pb
	Fe – Iron	27 to 33	mining ceased in 2005
	Mn – Manganese	27 to 30	no coupled production
<b>Czech Republic</b>	U – Uranium	0.48 to 0.52	no coupled production
	Fe – Iron	30	mining ceased in 2002
<b>Spain</b>	Ag – Silver	0.01169	with Au, Cu, Ge, Pb, Zn
	Au – Gold	0.000576	with Ag, Cu, Ge, Pb, Zn
	Cu – Copper	1.58	with Ag, Au, Ge, Pb, Zn
	Ge – Germanium	0.005	with Ag, Au, Cu, Pb, Zn
	Hg – Mercury	0.4	no coupled production
	Pb – Lead	1.48	with Ag, Au, Cu, Ge, Zn
	Sn – Tin	0.016	no coupled production
	Sr – Strontium	43.88	no coupled production
	Zn – Zinc	5.71	with Ag, Au, Cu, Ge, Pb
<b>Finland</b>	Cr – Chromium	35 to 36 (Cr <sub>2</sub> O <sub>3</sub> )	no coupled production
	Cu – Copper	1.17	with Zn and with Ni
	Au – Gold	0.00007	no coupled production
	Ni – Nickel	0.22	with Cu
	Zn – Zinc	0.49	with Cu
<b>France</b>	Al – Aluminium		reprocessed, gross weight
	Au – Gold		mine closed
	Ag – Silver		(probably with gold)
	U – Uranium		mine closed
<b>Germany</b>	Fe – Iron	11 to 14	no coupled production

	<b>Metal</b>	<b>Ore Grade [%]</b>	<b>Coupled Production</b>
<b>Greece</b>	Ni – Nickel	0.8	with Fe with Fe, Mn
	Zn – Zinc	9.0	with Pb, Au, Ag
	Pb – Lead	8 to 10	with Zn, Au, Ag
	Au – Gold	0.00036	with Pb, Zn, Ag
	Ag – Silver	0.02	with Pb, Zn, Au (also with barite and bentonite)
	Al – Aluminum	53 (alumina)	no coupled production
	Mn – Manganese	15 to 19	with Fe, Ni
<b>Hungary</b>	Mn – Manganese	26 to 27	no coupled production
<b>Ireland</b>	Pb – Lead	8 to 15	with Zn, Ag
	Zn – Zinc	13.6	with Pb, Ag
	Ag – Silver	0.5	with Pb, Zn
<b>Italy</b>	Au – Gold	0.00025	no coupled production
	Mn – Manganese	35.0	no coupled production
<b>Norway</b>	Co – Cobalt	1.38	no coupled production
	Fe – Iron	32.6	no coupled production
	Ti - Titanium	18.0	no coupled production
	Ni – Nickel	0.5	no coupled production
<b>Poland</b>	Pb – Lead	1.7	with Cu (33%) & Zn
	Cu – Copper	1.8 to 1.9	with Pb, Ag, Au
	Zn – Zinc	4.2	with Pb
	Au – Gold	0.0001	by-product of copper
	Ag – Silver		with Cu (mainly), with Pb, Zn (less)
	Cd – Cadmium		by-product of lead/zinc
<b>Portugal</b>	Cu – Copper	6	with Sn, Zn
	Sn – Tin		with Cu, Zn
	Zn – Zinc	8	with Sn, Cu
	W – Tungsten	0.25 (WO <sub>3</sub> )	no coupled production
	U – Uranium		no coupled production

	<b>Metal</b>	<b>Ore Grade [%]</b>	<b>Coupled Production</b>
<b>Romania</b>	Cu – Copper	0.6 to 1	with Pb, Zn (partly)
	Pb – Lead	0.4 to 1	with Zn, Cu (partly)
	Zn – Zinc	0.6 to 1.2	with Pb, Cu (partly)
	Au – Gold		associated with Pb, Zn
	Ag – Silver		associated with Pb, Zn
	Antimony		associated with Pb, Zn
	Bismuth		associated with Pb, Zn
	Cadmium		associated with Pb, Zn
	Mn – Manganese	16 to 25	no coupled production
<b>Slovakia</b>	Au – Gold	0.00014	--
	Cu – Copper	1	no coupled production
	Fe – Iron	26.68	no coupled production
<b>Sweden</b>	Cu – Copper	25 to 28 (concentrate)	-- with Au with Au, Pb, Zn with Pb, Zn
	Pb – Lead	5	with Zn with Cu,Zn with Cu, Au, Zn with Cu, Au
	Zn – Zinc	8	with Pb with Pb, Cu with Pb, Au, Cu
	Au – Gold		-- with Cu with Cu, Pb, Zn
	Ag – Silver		probably with Au
	<b>United Kingdom</b>	Pb – Lead	27 (concentrate)

Source: according to USGS Minerals Yearbook, Volume III, Area reports: International.

### **A.2.1 Iron ores**

The two main iron ores are hematite and limonite. Sweden is the only significant producer of iron ore within the EU and the only net exporter of ore. Iron ores are chiefly used to produce steel in integrated steel plants; cast iron is a minor part of production. Data for the extraction of iron ores are provided in good quality by national and international statistical sources and generally refer to gross ore production which commonly contains around 25% to 35% Fe. Iron ore concentrate contains around 64% Fe by weight.

## **A.2.2 Non-ferrous metal ores**

### **A.2.2.1 Copper ores**

There are several copper ores, but they all fall into two main categories: oxide ores and sulphide ores. Azurite, malachite, and chrysocolla are a few examples of oxide ores. Chalcocite, bornite, idaite, covellite, and chalcopyrite are all examples of sulphide ores. Currently, the most common source of copper ore is the mineral chalcopyrite, which accounts for about 50% of global copper production. Copper is used in the electrical, electronics, transportation, and construction industries. Within the EU, Poland has the largest mine production of copper, other relevant producers are Sweden, Portugal, and Finland. Copper ores mine production is usually reported in metal content. Typical copper content in gross ores is around 1%. Copper concentrates commonly contain between 20 and 40% copper by weight.

### **A.2.2.2 Nickel ores**

Two important nickel ores are the iron-nickel sulphides, pentlandite and pyrrhotite; the ore garnierite is also commercially important. The most important use of nickel is in steel alloys, it is further used in plating, both metals and plastics, and combined with copper in cupro-nickel alloys.

Within the EU, the only significant mine producer of nickel ores is Greece, smaller production is reported for Finland. Nickel ores mine production is usually reported in metal content. Typical metal content in gross ores is around 0.5%. Nickel concentrates typically contain 10% to 15% Ni by weight.

### **A.2.2.3 Lead ores**

The most common lead ore is galena, a sulphide. The other minerals of commercial importance are cerussite, a carbonate and anglesite, a sulphate. Lead also occurs in various uranium and thorium minerals, arising directly from radioactive decay. Commercial lead ores may contain as little as 3% lead, but a lead content of about 10% is most common. The ores are concentrated to 40% by weight or greater lead content before smelting. Lead is mainly used in lead-acid batteries, but also widely in architecture, plumbing, solder, radiation shielding, and insecticides. Within the EU, significant mine producers of lead ores are Ireland, Poland, and Sweden.

### **A.2.2.4 Zinc ores**

Chief sources of zinc are zinc blende, a sulphide ore (called also sphalerite or "Black Jack"), zincite, an oxide, calamine, a silicate, and smithsonite, the zinc carbonate. Zinc ores are

widely and abundantly distributed throughout the world. Chief use of zinc is for steel coating (galvanising), but it is also used as zinc die-casting, and alloyed with copper to make brass which is widely used in the electrical, engineering, and construction industries. Within the EU, significant mine producers of zinc ores are Ireland, Poland, and Sweden. Zinc ores mine production is usually reported in metal content. Metal contents in gross ores may be around 13% as in Ireland, but also significantly lower. Zinc concentrates typically contain around 55% Zn by weight.

#### **A.2.2.5 Tin ores**

The most important tin-bearing mineral is cassiterite. No high-grade deposits of this mineral are known. The bulk of the world's tin ore is obtained from low-grade alluvial deposits. The chief use of tin is to coat metals that are more susceptible to corrosion, especially steel. It is also widely used as an alloying agent (e.g. with lead to make pewter) and its use in solders is rapidly growing as it replaces lead. Tin chemicals are used as fungicides and other biocides. Within the EU, the only mine producer of tin ores is Portugal, where tin is produced in minor amounts along with copper from the same mine and therefore treated as a by-product. Tin concentrate from cassiterite typically contains 70-77% tin by weight.

#### **A.2.2.6 Gold, silver, platinum and other precious metal ores**

Gold: Native, or metallic, gold and various telluride minerals are the only forms of gold found on land. Native gold may occur in veins among rocks and ores of other metals, especially quartz or pyrite, or it may be scattered in sands and gravel (alluvial gold). Gold is highly valued as an investment commodity, in jewellery and in specialised electronic appliances. Gold mining in the EU represented a very low share of less than 1% of the world output in 2003. Sweden was the largest producer with about 6000 kg gold content followed closely by Spain. In Europe, gold mining is chiefly a by-product of base metal mining, for which the accounting procedure for coupled production is applied. In some cases, gold is however from sole gold mines like in Finland, Italy and Slovakia and has to be accounted as gross ore.

Silver: The principal silver ores are argentite, cerargyrite or horn silver, and several minerals in which silver sulphide is combined with sulphides of other metals. About three-fourths of the silver produced is a by-product of the extraction of other metals, copper and lead in particular. This also applies to silver mining in Europe. Silver is widely used in electronics although the most important uses are in photography (silver nitrate) and making mirrors.

Significant mine producers of silver within the EU are Poland, and, to a much lesser extent, Sweden. In Sweden, silver stems from a lead-zinc mine. Poland ranks among the major

world producers of silver and accounted for about 6% of world mine production in 2004. Silver mine production in the EU amounts to less than 2000 tonnes per year.

Platinum: There is no primary mine production in the EU. South Africa is the largest producer of platinum in the world. Platinum, often accompanied by small amounts of other platinum family metals, occurs in alluvial placer deposits in the Witwatersrand of South Africa, Colombia, Ontario, the Ural Mountains, and in western USA. Platinum is produced commercially as a by-product of nickel ore processing in the Sudbury deposit. The huge quantities of nickel ore processed makes up for the fact that platinum is present as only 0.5 ppm in the ore.

Other precious metal ores: These include the (other) Platinum Group Metals (PGM), palladium, rhodium, ruthenium, osmium and iridium. There is likewise no mine production in the EU.

Of the PGM family, platinum and palladium are the most commercially significant, having important applications as catalysts and in electronics and jewelry and as investment commodities.

#### **A.2.2.7 Bauxite and other aluminium ores**

The only important mineral source of aluminium is bauxite, which contains 40-60% aluminium oxide (Ayres et al. 2006). The chief uses of aluminium are in packaging, transportation, and construction. Greece is the most significant producer of bauxite within the EU followed by Hungary and France. However, on a global scale EU mine production is of minor importance. Data for the extraction of bauxite are provided in good quality by national and international statistical sources and generally refer to gross ore production.

#### **A.2.2.8 Uranium and thorium ores**

Minerals that contain uranium or thorium as an essential component of their chemical composition are called radioactive minerals. Examples are uraninite or thorite. Uranium is chiefly used as the fuel source for nuclear power stations and in weapons. Within the EU, a small amount of uranium is mined in the Czech Republic where the only mine has an output of around 500 tonnes metal content per year. Aside from this, there may be (unrecorded) production from decommissioning operations in France, Germany, and Spain. Typical metal content in gross ores is around 0.17%. Yellowcake concentrate is produced in all countries where uranium is mined and contains about 80% uranium oxide.

### **A.2.2.9 Other metal ores**

Other non-ferrous metal ores may include (according to the BGS commodity list for European mineral statistics): antimony, arsenic, bismuth, cadmium, chromium, cobalt, lithium, magnesium, manganese, mercury, molybdenum, rare earths (yttrium and scandium), selenium, strontium, tantalum (and niobium), titanium (ilmenite), tungsten, vanadium, zirconium. Some important metals in group A.2.2.9. are briefly described below.

Arsenic: is produced in minor quantities in Belgium, France, and Germany (altogether about 2000 tonnes). Arsenic is found native as the mineral scherbenkobalt, but generally occurs among surface rocks combined with sulphur or metals. Its principal uses are as compounds in wood preservatives and pesticides, and in semi-conductors as gallium arsenide.

Chromium: Finland is the only EU country with significant mine production of chromite, the only ore mineral of chromium. It is an essential component of stainless steel and other alloy steels. It is also used in superalloys and metal plating, as pigments and in refractories.

Lithium: is, in the EU, only mined in Portugal as Lepidolite mineral. Lithium may profitably be extracted from ores containing as little as 1% lithium (measured as lithium oxide). Some commercially important minerals are lepidolite, petalite, spodumene, and amblygonite. Lithium is also produced from brines such as those in Searles Lake, Calif., and in the Great Salt Lake, Utah. Its uses are as fluxes in the ceramics and glass industries, in lubricants, as alloying agent in primary aluminium, and in rechargeable batteries.

Magnesium: is a light metal commonly mined as magnesite in some EU countries. Although magnesium is found in over 60 minerals, only dolomite, magnesite, brucite, carnallite, talc, and olivine are of commercial importance. It is most commonly used in refractory bricks in furnaces, but also in fertilisers.

Manganese: is sometimes reported together with iron ores as iron-manganese ores. Manganese occurs principally as pyrolusite and to a lesser extent as rhodochrosite. Its principal use is in the steel industry as desulphuriser and as an alloy, further as an aluminium alloy, in dry-cell batteries, and in the chemical industry.

Mercury: is mined in minor amounts of around 770 tonnes in the EU (Spain and Finland). It is mainly used in electrical switches and other control apparatus, and in dental amalgam, but also in chlor-alkali plants and in batteries where the use is being phased out.

Strontium: Within the EU, only Spain has significant mine production of strontium minerals. Its dominant use is in the faceplate glass of cathode ray tubes where it blocks X-ray emissions. Other uses are in pigments, pyrotechnics, and fluorescent tubes.

Tungsten: mine production occurs in Austria and in Portugal at around 2000 tonnes metal annually. Metal contents may range from 0.25 to 2.5 % tungsten oxide; for Austria values of 1.8% have been reported. Its largest use is in cemented carbides in cutting tools, but also as an alloying agent with steel for tools and in superalloys. Its most familiar use is in light bulb filaments.

## Data compilation A.3 non-metallic minerals

### A.3.1. Ornamental or building stone

This category comprises almost any competent rock type that may be used in the form of shaped and/or sized blocks for either structural or decorative purposes. It includes marble and other calcareous ornamental or building stone (e.g. travertine, ecaussine, and alabaster), and granite, sandstone, and other ornamental or building stone (e.g. porphyry, basalt), as well as roofing stone.

Data are often given in cubic meters (m<sup>3</sup>) and have to be converted to tonnes (see table 12 for conversion factors).

**Table 12: Specific densities of ornamental and building stone**

	kg per cubic meter
Marble, solid	2563
Granite, solid	2691
Sandstone, solid	2323
Porphyry, solid	2547
Basalt, solid	3011
Stone (default value if no other specifications are available)	2500

Source: SIMETRIC

### A.3.2 Limestone, gypsum, chalk and dolomite

Limestone: In Europe, limestone is mostly used for cement production, followed by its use as crushed rock aggregate. Limestone requires special attention in the account for non-metallic minerals. Statistics often underreport amounts of limestone extracted for construction purposes, in particular for cement production. This position, however, commonly represents

a large mass flow accounting for a considerable share of DE of non-metallic minerals. To check and eventually correct for missing limestone extraction for cement production, the following estimation can be applied:

Estimate of limestone extraction based on (finished) cement production: The German Federal Institute for Geosciences and Natural Resources (BGR) explicitly reports limestone used for the production of Portland cement. Using corresponding production figures for cement from the BGR, a ratio of 1.19 tonnes of limestone for the production of 1 tonne of cement can be identified. The extraction of limestone can be calculated based on data for cement production in tonnes and the ratio of limestone to cement (equation (16)):

$$(16) \text{ Limestone for cement production [t]} = \text{cement production [t]} * 1.19$$

Data for cement production are reported for example in USGS statistics. A comprehensive source of global cement data is the European Cement Association (CEMBUREAU) which publishes yearly updates of global cement production, imports, exports and apparent consumption for individual countries. The World Statistical Review of 1998 (CEMBUREAU 1998) includes data for the period 1910-1995; later editions of this annual publication provide data in 10year intervals and yearly updates. For EU countries also production statistics can be used and should include PRODCOM-2007 items 26511210 (White Portland cement); 26511230 (Grey Portland cement including blended cement); 26511250 (Alumina cement) and 26511290 (Other hydraulic cements).

It is recommended to compare the estimated figure for limestone extraction for cement with the figure for limestone reported in statistics. The higher number should be selected as data for the domestic extraction of limestone (with a tolerance of about 10% in favour of using the original statistics figure). If limestone for other use than for cement is clearly indicated in statistics, this figure has to be added to the estimate for limestone for cement.

For minerals of category A.3.2. data are often reported in cubic meters (m<sup>3</sup>) and have to be converted to tonnes (see table 13 for conversion factors).

**Table 13: Specific densities of limestone and gypsum**

	kg per cubic meter
Gypsum, crushed	1602
Limestone, broken	1554
Limestone (default value if no other specifications are available)	1500

Source: SIMETRIC

Chalk is a soft, white, porous form of limestone composed of the mineral calcite. It is also a sedimentary rock. Uses are widespread and comprise blackboard chalk, to mark boundaries, in sports, applied to the hands or to instruments to prevent slippage, and as tailor's chalk.

Dolomite is the name of both a carbonate rock and a mineral consisting of calcium magnesium carbonate found in crystals. Dolomite rock (also dolostone) is composed predominantly of the mineral dolomite. Limestone which is partially replaced by dolomite is referred to as dolomitic limestone. Limestone and dolomite are commonly used as crushed-rock aggregate, for cement production, and for other industrial and agricultural uses. Limestone and dolomite are often combined in statistical reporting. They are, however, differentiated in statistics by CPA codes at the 5 digits level.

**Please note!** In case data for limestone are derived from an estimate described under A.3.2., it should be figured out if this estimate includes use of dolomite (for cement production). Data reported for dolomite under A.3.2 then eventually have to be corrected for double counts. It is recommended to consult a national expert for clarification of this issue.

For minerals of category A.3.2 data are often reported in cubic meters (m<sup>3</sup>) and have to be converted to tonnes (see table 14 for conversion factors).

**Table 14: Specific densities of chalk and dolomite**

	kg per cubic meter
Chalk, lumpy	1442
Dolomite, lumpy	1522
Chalk and dolomite (default value if no other specifications are available)	1500

Source: SIMETRIC

**A.3.3 Slate**

Slate is a fine-grained, homogeneous, metamorphic rock derived from an original shale-type sedimentary rock composed of clay or volcanic ash through low grade regional metamorphism. Slate can be made into roofing slates, also called roofing shingles. Fine slate can also be used as a whetstone to hone knives. Because of its thermal stability and chemical inertness, slate has been used for laboratory bench tops and for billiard table tops. Slate tiles are often used for interior and exterior flooring or wall cladding. Slate for construction purposes may be included in statistics as building or dimension stone (A.3.1)

and should, if possible included there. Depending on the predominant characteristics of slate, conversions from m<sup>3</sup> to tonnes may be performed as shown in table 15.

**Table 15: Specific densities of slate**

	kg per cubic meter
Slate, solid	2691
Slate, broken	1290-1450
Slate, pulverized	1362
Slate (default value if no other specifications are available)	1400

Source: SIMETRIC

**A.3.4 Gravel and sand**

There are two major groups of gravel and sand (sometimes also subsumed under the notion natural aggregates) which are distinguished by their principal uses:

Industrial sand and gravel: Industrial sands and gravels show specific material properties that are required for use in iron production and manufacturing including fire resistant industrial use, in glass and ceramics production, in chemical production, for use as filters, and for other specific uses. Statistical sources (e.g. the USGS) often report the amount of sand and gravel in industrial production processes explicitly.

Sand and gravel for construction: Sand and gravel for construction is used in structural engineering (e.g. buildings) and civil engineering (e.g. roads). Use of sand and gravel in structural engineering is mainly for the production of concrete. In civil engineering gravel is mainly used for different kinds of layers in road construction, as filling materials, in concrete elements and for asphalt production.

**Note:** Sand and gravel can contain considerable amounts of moisture (15-25%). In material flow accounts, sand and gravel is accounted for in dry weight. If necessary, an appropriate correction should be applied.

Statistics for sand and gravel may not report the total amount extracted for both industrial and construction use adequately. Often, only special sand and gravel for industrial use is included (see above). Statistics also may report numbers for sand and gravel for construction but not report total numbers due to e.g., limitations in the census. To find out if sand and gravel is not adequately reported or underestimated in statistical sources, the following checks can be performed:

The amount of sand and gravel per capita of the population in the respective year can be taken as an indicator. As a rule of thumb, if this amount is significantly below 1 ton per capita, it can be assumed that sand and gravel for construction purposes is not adequately reported and has to be estimated. Additionally stakeholders and experts concerned with this economic activity should be consulted to clarify the significance of the reported numbers. If no adequate statistical data are available, the total amount of sand and gravel extracted for construction can be estimated.

*Estimation of sand and gravel for construction:*

The following simple procedure to estimate the amount of sand and gravel used in construction takes into account the two most important uses of sand and gravel. It combines an estimate of sand and gravel required for the production of concrete (step 1) with an estimate of sand and gravel used in asphalt production (step 2). In step 3 the total amount of sand and gravel is calculated as the sum of the results obtained from step 1 and step 2. It is important to note that this is a conservative estimate which does not consider sand and gravel used as fillings and base material. In industrial countries, this approach typically underestimates the overall extraction of sand, gravel and crushed stone for construction by 20-40%.

*Step 1: Estimation of sand and gravel required for the production of concrete:* Concrete is a mixture of 6% air, 11% Portland cement, 41% gravel or crushed stone (coarse aggregate), 26% sand, and 16% water (PCA 2007). Thus, sand and gravel make up about 67% of the produced concrete. Based on these relations two ways for calculating sand and gravel required for concrete production are possible:

Method 1a) Estimation of sand and gravel based on the consumption of cement: The required input of sand and gravel to produce one ton of concrete is 6.09 times the input of cement (PCA 2007). Accordingly, sand and gravel input into concrete production can be calculated following equation (17):

$$(17) \text{ Sand and gravel input [t]} = \text{cement consumption [t]} \times 6.09$$

Cement consumption can be derived from data on production of and trade with cement using equation (18):

$$(18) \text{ Apparent cement consumption} = \text{cement production} + \text{cement imports} - \text{cement exports}$$

Data on cement flows can be obtained from statistical sources, e.g. the world statistical review of the European Cement Association (CEMBUREAU 1998, 2013). If industrial production and trade statistics are used, production includes PRODCOM-2007-items 26511210 (White Portland cement); 26511230 (Grey Portland cement including blended cement); 26511250 (Alumina cement) and 26511290 (Other hydraulic cements); Trade flows

include HS-CN-items 252321 (White Portland cement); 252329 (Portland cement excl. white); 252330 (Aluminous Cement); 252390 (Cement weather or not coloured excl. Aluminous and Portland cement).

Method 1b) Alternatively, sand and gravel can be estimated on the basis of concrete production data using equation (19):

$$(19) \text{ Sand and gravel input [t] = concrete production [t] } \times 0.67$$

Data on concrete production can be obtained from production statistics (PRODCOM-2007-item 26631000 Ready-mixed concrete); in general, method 1a tends to underestimate the amount of sand gravel, because concrete reported in statistics commonly refers to transport concrete and does not include concrete produced directly at the construction site. If method 1 is used, clarification of the quality of concrete production data is required.

*Step 2: Estimation of sand and gravel for asphalt production:* Asphalt or asphalt concrete is a composite material commonly used in construction projects, above all for road surfaces. Asphalt consists of bitumen, a product of the petrochemical industry, which is mixed with mineral aggregate (gravel, crushed stone, etc.). To encompass at least some of the sand and gravel used in road construction and maintenance sand and gravel demand for asphalt production can be estimates by combining data on bitumen consumption and the ratio of bitumen to sand and gravel in asphalt, which is typically around 1:20. Data on bitumen production are reported for example in IEA's international energy statistics database or the United Nations energy statistics database (UNSD 2008). Sand and gravel input is calculated using equation (20):

$$(20) \text{ Sand and gravel input [t] = bitumen consumption [t] } \times 20$$

*Additional information: Estimation of sand and gravel for road layers (freezing protection and carrying layers):*

Also information on the length of newly built roads (by type of road and year) can be used to estimate the amount of sand and gravel used in the construction of roads. Data on the length and enlargement of the road network are commonly provided by national transport or road statistics. Data for the EU Member States and other countries are e.g. available from the publication "EU energy and transport in figures" (DG TREN 2008). The International Road Federation publishes the world road statistics, which could also be used as a data source; information on road length is also available from the World Development Indicators database (The World Bank Group 2014). Quality of road length data and comparability across

countries is, however, quite poor and this method should only be applied when expert knowledge is available.

In addition to information on the length of the road network, data on the amount of sand and gravel required to build one kilometre of a certain road type have to be acquired. The following table 16 provides examples for Germany but sand and gravel requirements for the construction and maintenance can vary significantly across regions and countries:

**Table 16: Requirements of sand and gravel per km of road construction in Germany**

	tonnes sand and gravel per km		Reference data	
	for construction	for annual maintenance	Average width in m	Total length in km
	Germany	Germany	Germany	Germany
Highways	28,383	518	24.4	12,531
National roads	9,692	151	8.8	40,711
Federal state roads	8,719	76	7.5	86,597
District roads	6,777	65	6.5	91,520
Local roads	5,729	67	5.5	460,000
<b>All roads</b>	<b>6,886</b>	<b>81</b>	<b>6.4</b>	<b>691,359</b>

Sources: Ulbricht 2006; Steger et al. 2009.

*Step 3 Finalization and cross check:* Estimated figures for sand and gravel for concrete production (step 1) and sand and gravel for asphalt production (step 2) are finally added and compared with the figure for sand and gravel reported in statistics. The higher number should be selected as data for the domestic extraction of sand and gravel for construction (with an eventual tolerance of about 10% in favour of using the original statistics figure). In case sand and gravel for industrial uses is given as a specific position in statistics, this figure has to be added to the estimated figure.

In this category of minerals, data may be given in cubic meters (m<sup>3</sup>) and have to be converted to tonnes. Reference values are given in table 17.

**Table 17: Specific densities of sand and gravel**

	kg per cubic meter
Gravel, loose, dry	1522
Gravel, with sand, natural	1922
Gravel, dry 1,3 to 5,1 cm	1682
Gravel, wet 1,3 to 5,1 cm	2002
Sand, wet	1922
Sand, wet, packed	2082

	kg per cubic meter
Sand, dry	1602
Sand, loose	1442
Sand, rammed	1682
Sand, water filled	1922
Sand with Gravel, dry	1650
Sand with Gravel, wet	2020
Sand and gravel (default value if no other specifications are available)	1900

Source: SIMETRIC

### A.3.5 Clays and kaolin

Kaolinite is a clay mineral, rocks that are rich in kaolinite are known as china clay or kaolin. Other kaolinic clays are kaolin minerals such as kaolinite, dickite and nacrite, anauxite, and halloysite-endellite.

The largest use is in the production of paper, as it is a key ingredient in creating “glossy” paper (but calcium carbonate, an alternative material, is competing in this function). Other uses are in ceramics, medicine, bricks, as a food additive, in toothpaste, in other cosmetics, and since recently also as a specially formulated spray applied to fruits, vegetables, and other vegetation to repel or deter insect damage.

In statistics, kaolin may be grouped together with other clays under the heading “industrial or special clays”. Other industrial or special clays can be: ball clay, bentonite, sepiolite and attapulgite, ceramic clay, fire clay, flint clay, fuller’s earth, hectorite, illite clay, palygorskite, pottery clay, refractory clay, saponite, sepiolite, shale, special clay, slate clay.

Kaolin and other special clays are commonly well documented in statistics. Data may be given in cubic meters (m<sup>3</sup>) and have to be converted to tonnes (see table 18).

**Table 18: Specific densities of clay**

	kg per cubic meter
Clay, dry excavated	1089
Clay, wet excavated	1826
Clay, dry lump	1073
Clay, fire	1362

	kg per cubic meter
Clay, wet lump	1602
Clay, compacted	1746
Clay (default value if no other specifications are available)	1500

Source: SIMETRIC

Distinct from special or industrial clays are common clays and loams for construction purposes, in particular for bricks and tiles. These are often not or under-represented in statistics. To check for this, the following estimation procedure developed by the Federal Statistical Office Germany may be applied (Klinnert 1993).

(a) For the production of full and lug bricks 2.2 tonnes crude clay are required to produce 1 m<sup>3</sup> of bricks. Full and lug bricks include PRODCOM-2007-items 26401110 (non-refractory clay building bricks); 26401113 (ceramic bricks and blocks for common masonry: formed units, with or without perforation, for walls with rendering or cladding); 26401115 (ceramic facing bricks: formed units, with or without perforation, for use without rendering); 26401117 (ceramic paving bricks: formed units for floor and road surfacing).

(b) For the production of roof bricks 1.05 tonnes crude clay are required to produce 1 t of bricks, and 2.73 kg crude clay are required to produce one single roof brick respectively. Roof bricks include PRODCOM-2007-items 26401130 (non-refractory clay flooring blocks); 26401250 (non-refractory clay roofing tiles); 26401270 (non-refractory clay constructional products (including chimneypots, cowls, chimney liners and flue-blocks, architectural ornaments, ventilator grills, clay-lath; excluding pipes, guttering and the like).

(c) For the production of ceiling bricks (in case reported this way): 0.22 tonnes crude clay are required to produce 1 m<sup>2</sup> of bricks, and 2.2 t crude clay are required to produce 1 m<sup>3</sup> of bricks respectively.

The overall estimation result is compared with the figure for common clays and loams extraction reported in statistics (excluding industrial or special clays). The higher number should be selected as data for the domestic extraction used of common clay and loam (with an eventual tolerance of about 10% for using the original statistics figure).

### A.3.6 Chemical and fertiliser minerals

This group of minerals mainly comprises:

Natural calcium or aluminium calcium phosphates, often combined under the heading “phosphate rock”. Most of it (over 90%) is used to produce fertiliser; the remainder is used in the production of detergents, animal feedstock, and many other minor applications.

**Note:** Under phosphate mineral statistics may report gross ore of phosphate production, phosphate rock or produced phosphate. In MFA accounts the mined gross ore should be reported which typically contains about 15-30% phosphate rock, which contains about 30% phosphate (P<sub>2</sub>O<sub>5</sub>).

Carnallite, sylvite, and other crude natural potassium salts are often combined under the heading “potash”. Potassium is essential in fertilisers and is widely used in the chemicals industry and in explosives. Data for potash are often reported in K<sub>2</sub>O contents. In this case, as for metals, the run-of-mine production has to be calculated to obtain the used domestic extraction. Germany is by far the biggest producer of potash in the EU and the third biggest in the world. The K<sub>2</sub>O content in run of mine production of potash in Germany is about 55%.

Unroasted iron pyrite which is an iron disulfide. Pyrite is used for the production of sulphur dioxide, e.g. for the paper industry, and in the production of sulphuric acid, though such applications are declining in importance.

Crude or unrefined sulphur is a fundamental feedstock to the chemical industry. **Please note!** Not all domestic sulphur production is accounted for in category A.3.6. For the purpose of MFA three principle types of sulphur can be distinguished: (1) Sulphur from mining: This sulphur should be accounted for in category A.3.6. (2) Sulphur produced in the refinery through desulphurisation of petroleum resources. This sulphur is included in the amounts of extracted petroleum resources and should not be reported under A.3.6. (3) In some cases sulphur can occur as an unused by-product of the extraction of petroleum resources. This sulphur is considered unused extraction and is not accounted for in the MFA tables.

Other chemical minerals are mainly: Baryte, used in a variety of industries for its properties of high specific gravity, witherite, a barium carbonate mineral which is the chief source of barium salts and is mined in considerable amounts in Northumberland. It is used for the preparation of rat poison, in the manufacture of glass and porcelain, and formerly for refining sugar. Borates are chemical products from borate minerals, which are e.g. used as wood preservatives. Borate minerals contain the borate anion, BO<sub>3</sub><sup>3-</sup>, the most common borate mineral is boron. Fluorspar, i.e. the mineral fluorite mainly a source of fluorine, kieserite, a mineral made of magnesium sulphate and epsomite, a hydrous magnesium sulphate mineral, alunite or alumstone, pozzolana, and other mineral substances n.e.s.

### **A.3.7 Salt**

This material group concerns sodium chloride. Salt may be produced from rock salt, brine or seawater. It is used for human consumption, in the chemical industry, or to 'grit' roads to prevent the formation of ice.

### **A.3.8 Other mining and quarrying products n.e.c.**

This is a diverse group that essentially comprises all minerals not covered by the previous groups. Some of the minerals that are allocated to A 3.8 are listed below.

Bitumen and asphalt, natural asphaltites and asphaltic rock: The largest use of asphalt is for making asphalt concrete for road surfaces, which accounts e.g. for approximately 80% of the asphalt consumed in the United States. Only natural asphalt and bitumen is accounted for in this category. Most of the bitumen, tar and asphalt are products of the petrochemical industry and are not considered domestic extraction.

Precious and semi-precious stones (excluding industrial diamonds): Have no relevance for domestic extraction in the EU.

Industrial diamonds comprise a number of different stones such as pumice stone, emery; natural corundum, natural garnet and other natural abrasives used for various industrial purposes.

Graphite, a stable form of pure carbon, is mainly used in refractories.

Quartz and quartzite are special qualities of silicium used e.g. in the optical industry or in metal manufacturing.

Siliceous fossil meals like Kieselgur, Tripolite, Diatomite and other siliceous earths, used e.g. as absorption agent or material for heat insulation.

Asbestos, a fibrous mineral, is nowadays restricted in its use due to serious hazard to health.

Steatite and talc are magnesium silicate minerals, used for several industrial purposes.

Feldspar, essential component of glass and ceramic manufacture.

### **A.3.9 Excavated soil, only if used (e.g. for construction work)**

Excavated soil that is used in construction as material input conceptually has to be considered as used extraction. However, no standardized estimation procedure for this material flow is available. In its economy-wide MFA for 1980 to 1998, the Italian Statistical

Office has reported soil from excavation activities. For further details, please refer to Barbiero et al. (2003).

## **Specific issues related to DE of minerals**

### **Crushed rock (or crushed or broken stone)**

Several statistical sources use the category “crushed rock” or “crushed stone”. Crushed rock is commonly produced as broken natural stones for road-, railway-, waterway-, and buildings construction. A range of natural stone types can be used to produce crushed rock. These include the types explicitly addressed in this guide under A.3. 2 (limestone, gypsum, chalk, and dolomite) and under A.3.8 (other mining and quarrying products n.e.c.). In addition, crushed rock may comprise other natural stones like sandstone, volcanic stones, basalt, granite, quartzite, gneiss, and others.

The classification of stone minerals described in this guide, is not fully consistent with a classification that specifies crushed stone (or rock), as is often done in national and international mining statistics. Possible classifications one may find in statistical sources may include:

- statistical data include gravel under crushed rock, or vice versa, without distinction;
- statistics report building stone which may comprise, but not show separately, dimension stone and crushed rock;
- data for limestone are reported as such but also included under crushed rock, so that double counting occurs.

It is therefore difficult at times to judge if the production of crushed stone is complete and without doubles counts. In the first place, we recommend acquiring data for the domestic extraction of non-metallic minerals as described in this guide. Crushed rock should then be mainly covered by limestone, gypsum, chalk, and dolomite, and bitumen and asphalt rock.

The total of these positions may then be compared with the total number for crushed rock in national statistics or alternatively in the BGS European Mineral Statistics. In case the number for total crushed rock is considerably higher than the sum of related minerals accounted for as described in this guide, the difference may be taken as an estimate for additional domestic extraction used of crushed rock which cannot be further identified.

**Please note!** If this is the case please add the additional amount of crushed stones to A.3.4 and add a footnote stating what amount of additional crushed stone had been added and by which method it has been estimated.

## Fossil energy carriers

**Table 19: Domestic extraction of Fossil energy carriers**

1 digit	2 digit	3 digit
A.4 Fossil energy carriers		
	A.4.1	Brown coal
	A.4.2	Hard coal
	A.4.3	Petroleum (including natural gas liquids)
	A.4.4	Natural Gas
	A.4.5	Peat
	A.4.6	Oil shale and tar sands

### Introduction

Petroleum resources and other fossil energy carriers are materials formed in the geological past from biomass. They comprise solid, liquid, and gaseous materials.

Economic value: Petroleum resources are bulk raw materials of medium economic value (less than 1000 €/t).

Socio-economic use: The largest fraction of petroleum resources is used for the provision of energy, but they may also be employed as raw materials for industrial processes (e.g. for the production of organic chemical compounds and synthetic materials or fibres).

Environment: The extraction of petroleum resources is related to a range of environmental hazards. The combustion of fossil fuels is one of the most prominent socio-economic activities contributing to global warming and to different types of air pollution. The extraction and transportation of petroleum resources is related to the pollution and destruction of terrestrial and marine ecosystems.

The extraction of petroleum resources per capita varies according to geological deposits and their share of total DE ranges from zero to 40% in the 27 EU countries in the year 2000 (Eurostat 2009b). In European countries, extraction averages at 2 t/cap and ranges between zero and 10 t/cap. Coal accounts for roughly half of total DE of fossil energy carriers, followed by natural gas (30%) and oil (20%). The extraction of peat only has regional significance.

## Data sources

Different sections of national statistics provide data on the extraction of petroleum resources and other fossil energy carriers: mining statistics, industrial production statistics, and energy statistics. Data quality is usually very high for all subcategories.

International sources: A number of international data sources provide information about DE of petroleum resources and fossil energy carriers. The most prominent are the database of the International Energy Agency (IEA 2014), the United Nations Industrial Commodity Production Statistics, the United Nations Energy Statistics; the data collections of the United States Geological Survey (USGS). All of these databases report the extraction of the various types of coal, crude oil, and natural gas and can be used for the compilation of material flow accounts. The reported values may differ slightly across sources, above all due to differences in definition or unit conversion procedures.

Data on the extraction of all petroleum resources and other fossil energy carriers from national and international statistical sources can usually be integrated into MFA accounts without further processing. In some cases, conversion from values given in volume or energy content into weight may be required. As the technical characteristics of petroleum resources vary from region to region, country specific conversion factors should be applied.

## Conventions

**Terminology and classification:** The terminology and classification of petroleum resources and other fossil energy carriers used in this guide by and large follow the terminology used by the IEA and may differ from the terminology used in national statistics. For further details, refer to the OECD/IEA/Eurostat Energy Statistics Manual (OECD/IEA/Eurostat 2005).

**System boundaries:** According to the conventions of MFA only extracted petroleum resources without inert matter are considered. Re-injected or flared fractions of crude oil or natural gas are considered unused extraction and not accounted for under domestic extraction. Petroleum resources used within the extraction industries are to be included.

## Data compilation

### A.4.1 Brown coal

This category includes lignite or brown coal (i.e., non-agglomerating coal with a gross calorific value of less than 17.4 MJ/kg and greater than 31 per cent volatile matter on a dry mineral matter free basis) and sub-bituminous coal (i.e., non-agglomerating coals with a gross calorific value between 17.4 MJ/kg and 23.9 MJ/kg, containing more than 31 per cent volatile matter on a dry mineral matter free basis).

### A.4.2 Hard coal

This includes all anthracite coals, bituminous coals and coking coal with a gross calorific value greater than 23.9 MJ/kg on an ash-free but moist basis.

## 4.3 Crude oil and natural gas liquids

Crude oil is a mineral oil consisting of a mixture of hydrocarbons of natural origin. Natural gas liquids are liquid hydrocarbon mixtures, which are gaseous at reservoir temperatures and pressures, but are recoverable by condensation and absorption. Natural gas liquids (NGL) are classified according to their vapour pressure as condensates, natural gasoline or liquid petroleum gas (LPG).

## 4.4 Natural gas

Natural gas comprises gases, occurring in underground deposits, whether liquefied or gaseous, consisting mainly of methane. It includes both "non-associated" gas originating from fields producing only hydrocarbons in gaseous form and "associated" gas produced in association with crude oil as well as methane recovered from coal mines (colliery gas).

Production is measured after purification and extraction of NGL and sulphur and excludes re-injected gas, quantities vented or flared (so called total dry production). Natural gas is often reported in volume or energy content and has to be converted into metric tonnes by applying region specific factors (see Table 20 for average values).

**Table 207: Calorific value and density of natural gas of fossil energy carriers**

	kg / m <sup>3</sup> (standard cubic meter at 15 °C)	GCV [MJ/kg]	GCV [MJ/m <sup>3</sup> ]
Natural gas (range)	0.76-0.83	36-55	30-45
Natural gas (default value)	0.8	50	40

Source: derived from OECD/IEA/Eurostat 2005

## 4.5 Peat

Peat is a combustible soft, porous or compressed, fossil sedimentary deposit of plant origin with high water content which may be used for combustion or agricultural purpose.

### A.4.6 Oil shale and tar sands

This category includes oil shale (a sedimentary rock containing kerogen, a solid organic material) and tar sands (naturally occurring bitumen-impregnated sands that yield mixtures of liquid hydrocarbon and that require further processing other than mechanical blending before becoming finished petroleum products) for direct combustion and as inputs into other transformation processes (these are only of regional significance).

**Note:** Different technologies are applied to extract oil from oil sand (e.g. in situ extraction, surface mining). In the case of surface mining, large amounts of oil sand are extracted and processed. In this case not only the produced oil should be accounted for, but the total extracted mass of oil sand should be reported separately from the produced oil. Typically 2 tons of oil sand are extracted per barrel of oil.

## Tables B and C: Imports and exports

**Table 21: Classification of trade flows**

1 digit	2 digit	3 digit
B.1 Biomass and biomass products		
	B.1.1 Primary crops	B.1.1.1 Cereals, primary and processed B.1.1.2 Roots, tubers, primary and processed B.1.1.3 Sugar crops, primary and processed B.1.1.4 Pulses, primary and processed B.1.1.5 Nuts, primary and processed B.1.1.6 Oil bearing crops, primary and processed B.1.1.7 Vegetables, primary and processed B.1.1.8 Fruits, primary and processed B.1.1.9 Fibres, primary and processed B.1.1.10 Other crops, primary and processed
	B.1.2 Crop residues,	B.1.2.1 Straw B.1.2.2. Other crop residues
	B1.3. Fodder crops and grazed biomass	B.1.3.1 Fodder crops (incl. biomass harvested from grassland) B.1.3.2. Grazed biomass (not applicable)
	B.1.4 Wood and wood products	B.1.4.1 Timber, primary and processed B.1.4.2 Wood fuel and other extraction, primary and processed
	B.1.5 Fish capture and other aquatic animals and plants, primary and processed	B.1.5.1 Fish capture B.1.5.2 All other aquatic animals and plants
	B.1.6 n.a.	
	B. 1.7 Live animals other than in 1.5., meat and meat products	B. 1.7.1 Live animals other than in 1.5. B. 1.7.2 Meat and meat preparations B. 1.7.3 Dairy products, birds eggs, and honey B. 1.7.4 Other products from animals (animal fibres, skins, furs, leather etc.)
	B. 1.8 Products mainly from biomass	
B.2 Metal ores and concentrates, primary and		

1 digit	2 digit	3 digit
processed		
	B.2.1 Iron ores and concentrates, iron and steel	
	B.2.2 Non-ferrous metal ores and concentrates, primary and processed	
		B.2.2.1 Copper
		B.2.2.2 Nickel
		B.2.2.3 Lead
		B.2.2.4 Zinc
		B.2.2.5 Tin
		B.2.2.6 Gold, silver, platinum and other precious metal
		B.2.2.7 Bauxite and other aluminium
		B.2.2.8 Uranium and thorium
		B.2.2.9 Other metals
	B.2.3 Products mainly from metals	
B.3 Non-metallic minerals, primary and processed		
	B.3.1 Ornamental or building stone	
	B.3.2 Limestone and gypsum, chalk and dolomite	
	B.3.3. Slate	
	B.3.4 Gravel and sand	
	B.3.5 Clays and kaolin	
	B.3.6 Chemical and fertilizer minerals	
	B.3.7 Salt	
	B.3.8 Other mining and quarrying products n.e.s.	
	B.3.9 n.a.	
	B.3.10 Products mainly from non metallic minerals	
B.4 Petroleum resources, primary and processed		
	B.4.1 Brown coal	
	B.4.2 Hard coal	
	B.4.3 Petroleum (including natural gas liquids)	
		B.4.3.1 Traded petroleum and petroleum products
		B.4.3.2 Adjustment for residence principle (Fuel for land water and air transport): Fuel bunkered by resident units abroad (Table B); Fuel bunkered by non-resident units domestically (Table C)
	B.4.4 Natural Gas	
	B.4.5 Peat	
	B.4.x Oil shale and tar sands	
	B.4.6 Products mainly from petroleum products	

## Introduction

Two types of system boundaries are relevant in economy-wide MFA (see introduction):

- (1) The functional boundary between the economy and the natural environment determines the definition of DE and DPO.
- (2) The economic boundary between the focal national economy (i.e. the economy for which the MFA is compiled) and other national economies determines the definition of imports and exports.

This chapter deals with the treatment of import and export flows in MFA. The OECD, following recommendations made by the UN, provides the following definition for foreign trade: “The international merchandise trade statistics record all goods which add to or subtract from the stock of material resources of a country by entering (imports) or leaving (exports) its economic territory. Goods simply being transported through a country (goods in transit) or temporarily admitted or withdrawn (except for goods for inward or outward processing) do not add to or subtract from the stock of material resources of a country and are not included in the international merchandise trade statistics” (OECD 2006). Due to the territorial definition of foreign trade, data recorded in national trade statistics do not fully comply with the residence principle and some adjustments may be required which are discussed on section “Adjustments for residence principle” below.

As opposed to domestically extracted materials, traded goods represent commodities and products at different stages of processing and span from basic commodities such as unmilled cereals or ore concentrates to semi-manufactured goods such as worked wood or steel ingots and finally to finished goods such as technical appliances or furniture.

**Please note!** Raw materials, as defined in Material Flow Accounting (see chapter “fundamentals”), per definition cannot be traded. Only those materials which are crossing the border between the environment and the economy are considered as raw materials. Conversely traded goods per definition are crossing the border between national economies, thus they have already achieved a status of a good, i.e. they represent a specific exchange value. In general traded goods have undergone some kind of processing, be it of purification, concentration or transformation of the raw materials into the goods. We therefore distinguish

between basic commodities, semi-manufactured goods and final products to indicate the stage of processing among traded goods.

In MFA, all traded goods are accounted for with the mass they have at the point in time that they cross the administrative borders. This corresponds to the conventions of the foreign trade statistics provided by the UN and the OECD: “Goods should be included in statistics at the time when they enter or leave the economic territory of a country. In the case of customs-based data collection systems, the time of recording should be the date of lodgement of the customs declaration. Lists of goods to be included, and recorded separately, and to be excluded should be provided. Specific goods are to be excluded from detailed international merchandise trade statistics but recorded separately in order to derive totals of international merchandise trade for national accounts and balance of payments purposes” (OECD 2006).

Total imports constituted one fifth of the direct material input ( $\text{DMI} = \text{DE used} + \text{Imports}$ ) into the EU-15 in 1970 and increased to one quarter until 2000. In absolute terms imports into the EU-15 amounted to 1.4 billion tonnes and exports from the EU-15 to 0.4 billion tonnes in 2000, while the physical quantity of the intra EU trade (i.e. the trade between EU member states) was 11 billion tonnes. Oil, ores and coal represent the largest fractions of imports into the EU-15, together these commodities cover 70 % of the physical import volume. In the Physical Trade Balance ( $\text{PTB} = \text{Imports} - \text{Exports}$ ), this pattern is accentuated with the three material categories oil, coal, and ores covering 80 % of net imports (EU-15 in 2000). Exports, on the other hand, are still at a considerably lower level (roughly one quarter of imports), but they increased more quickly over the last three decades. Imports per capita ranged from 2 t in Romania to 26 t in Belgium in 2005. Exports per capita were lowest in Romania with 1.2 t and highest in Belgium with 20 t in the year 2005 (all data for EU15 in the year 2000 from Weisz et al. 2004, EU27 in 2005 from Eurostat 2009b).

## **Data structure and sources**

Foreign trade statistics is the basic data source for import and export flows in EW-MFA. Due to the territorial definition of foreign trade, data recorded in national trade statistics do not fully comply with the residence principle and some adjustments may be required which are discussed in section “Adjustments for residence principle” below. Import and export data are available in foreign trade statistics which are compiled on the national level and additionally gathered in international databases. In general, priority should be given to national data; international data should only be resorted to as a second choice. As the specifics of national foreign trade statistics may not allow for generalisation, we here refer to international databases and their characteristics to explain the main issues regarding the compilation of import and export data within an economy wide MFA.

## **International nomenclatures and classification of traded commodities**

On the international level, two nomenclatures are mainly used: Harmonised System (HS) – Combined Nomenclature (CN) and Standard International Trade Statistics (SITC). Most national data follow one of these nomenclatures. Therefore this guide and the MFA tables are based on these classifications. National statistics that differ from these classifications cannot be covered in this guide and must be dealt with on an individual basis.

Trade statistics include between 3000 (SITC) to 10.000 (CN) items of traded goods organised by classification schemes. The Harmonized System (HS) classification is promoted by the World Customs Organisation and includes over 5000 commodity groups identified by 6-digit codes (referred to as “sub-headings”), aggregated to the 4-digit level (more than 1200 groups, referred to as “headings”), and to the 2-digit level (almost 100 groups, referred to as “chapters”). HS was first introduced in 1988, revisions were adopted in 1992, 1996, and 2002. The Combined Nomenclature (CN) was developed by the European Community and is based on the HS nomenclature but comprises another subdivision with 8-digit codes.

The SITC is promoted by the UN and structured along 5 hierarchical levels: Level 1 (1-digit codes) includes 10 sections, level 2 (2-digit codes) 67 divisions, level 3 (3-digit codes) 261 groups, level 4 (4-digit codes) 1033 subgroups, and level 5 (5-digit codes) 3121 items. SITC was first introduced in 1961 and revised in 1981 (revision 2) and 1994 (revision 3). A new revision (revision 4) has recently been introduced. Correspondence tables exist between the nomenclatures (e.g. from the UN: <http://unstats.un.org/unsd/cr/registry/regot.asp?Lq=1>).

## **International databases**

On the European level, the foreign trade database “Comext” is maintained by Eurostat. It includes data for the EU Member States from 1976 onwards or beginning with the year of accession, respectively. Data is reported in CN and SITC nomenclature. Comext also reports data on extra EU27 trade from 1999 onwards (domain EU27 since 1999).

On the international level, the UN keeps the database “Comtrade” in which foreign trade data for more than 140 countries are summarized and reported from 1960 onwards depending on national reporting. Data is classified according to HS and SITC nomenclature.

In international MFA studies, FAOSTAT is often used as source for trade with products of agriculture, forestry and fisheries. The energy statistics database of the International Energy Agency as well as the United Nations energy statistics database report data on trade with fossil energy carriers and products of the petrochemical industry. Data from COMTRADE are

used for all other products (i.e. products made of minerals and metals, most manufactured goods).

### **Structure of trade statistics**

**Units of measurement:** Foreign trade data are usually reported in monetary and physical units. The standard physical unit is kilograms or metric tonnes measured at the point in time in which a good crosses an administrative border. For some commodities, data are reported in other physical units such as length (metres), area (square metres), volume (cubic metres, litres), numeric units (pieces, pairs, dozens, packs), or, for electricity, in kilowatt-hours (United Nations 2004). In the EU, “the most common unit of measurement of quantity used in the collection of trade data is the net mass. This was collected for all goods until 1997. Since then it has not been required for certain categories of goods in intra-EU trade when it is not the most suitable quantity unit. As from 2006 member states may not collect the net mass when the supplementary unit (i.e. a unit other than kilograms) is requested” (Eurostat 2006: 18).

It is possible to search Eurostat’s Comext database selecting either metric tonnes or other units, i.e. “supplementary units”. In case “metric tonnes” are selected, all trade data available in this unit are displayed. Any trade flows that are only reported in other units are not displayed in the results of such a query.

The UN Comtrade database handles this issue in a different manner. Here, no results in physical units are returned if the item for which the query was run has subordinate categories which are reported in supplementary physical units. Using UN Comtrade data therefore requires defining an intermediate level of aggregation of trade classifications at which sufficient physical data is returned (see section on data compilation). Usually physical data appear only at the 3 digit level or lower. FAOSTAT, IEA and UN energy statistics database report trade flows in mostly tons, with some exceptions (i.e. certain forestry products are reported in scm; natural gas in TJ)

**Partner countries:** Import and export data are reported according to the countries of origin or destination, respectively. In some databases, it is also possible to select country-aggregates as trade partners.<sup>6</sup>

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<sup>6</sup> Comext: For countries in the EU, it is necessary to differentiate between trade flows between member states and those with non-member countries. This is important because in the calculation of the EU’s aggregated foreign trade flows only the imports to and exports from non-EU countries are considered. In Comext, outward flows from a Member State to a non-member country are called “exports”, outward flows from one Member state to another are called “dispatches”. Inward flows from

**Transit flows:** The reported flows of foreign trade statistics are imports and exports. Most commonly, foreign trade statistics also distinguish “transit” flows, i.e. imports that are exported again without any processing occurring within the country and thus to which no value is added before export. In the EU and the corresponding database Comext, “goods in transit across the European Union area are not included in trade statistics” (Eurostat 2006: 9). In the UN Comtrade database, transit flows are displayed as “re-imports” and “re-exports” in addition to imports and exports. As import and export data include re-imports and re-exports, these have to be subtracted from the totals.

## **Conventions, conversions**

In this section the most important conventions for the accounting of physical imports and exports are described.

Additional categories compared to DE: Unlike DE, traded goods include basic commodities and manufactured goods but no raw materials. Thus, commodities and goods become relevant that would not be considered in calculating domestic extraction, e.g. pork or milk. In Material Flow Accounting every traded good is considered unless it is immaterial, i.e. has no weight as e.g. electricity.

Packaging materials: According to EU regulation as well as standard international trade statistics, merchandise trade is reported in net weight units, i.e. excluding packaging materials. However, in some cases, trade statistics might also be reported in gross weight - especially for some finished goods where the commodity may be reported at the weight it has upon being sold. This often includes packaging materials, e.g. for marmalade sold in a glass (Eurostat 2001: 49).

From a purely conceptual point of view, packaging materials should be accounted for in MFA. Practically, though, packaging materials often are of negligible importance. A German study on traded packaging materials revealed that the amount of packaging materials in imported goods was only 0.5% of the imported tonnes (GVM 2005). Considering the minor importance and the huge efforts an estimation of packaging materials in traded goods would take, the Eurostat MFA task force recommended that no additional estimation of packaging materials needs to be performed.

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a non-member country are called “imports”, inward flows from another Member State are called “arrivals” (Eurostat 2006: 6).

**Please note!** In any case, though, it should be verified whether trade flows are reported in net or gross weight and any changes in reporting conventions during the covered time period should be identified, in order to avoid flaws in time series of physical trade data.

Transit: In MFA commodities that are simply transported through a country, i.e. transit, are not considered as imports or exports. Note also the discussion on transit flows above.

## **Confidential trade**

Due to reasons of confidentiality, data that would reveal information pertaining to individual firms is suppressed on the respective aggregation level but reported on the next higher level where confidentiality can be adequately ensured.

In those databases in which the highest aggregation level is also reported in mass units (e.g. Comext), this can lead to discrepancies between reported trade flows if data on some flows are suppressed on lower aggregation levels. Thus, when working with different levels of aggregation, the sum of total traded masses at an intermediate level of aggregation may be lower than the total mass reported on the highest aggregation level.

In those databases which do not provide physical values on higher aggregation levels (due to the variance among physical units in the lower levels), the amount of suppressed confidential data cannot be precisely determined. The magnitude of these suppressed amounts can vary significantly over time and also between countries. In compiling an MFA, the difficulty of determining these flows must be taken into consideration. In some cases, it will be necessary to include an estimation of suppressed data based on country specific information, or else request aggregates of the confidential data from the respective unit of the national statistical office.

## **Conversions**

From a conceptual point of view in all cases where units other than standard physical units (see above) are given, reported data have to be converted into tonnes by either using national conversion factors or other conversion factors such as those proposed in Annex 3c which lists unit mass conversion factors for a large number of traded commodities based on CN classification.

**Please note!** In actual practise it should also be considered that the amount of trade data reported in units other than tonnes can substantially vary from country to country. Therefore no "one size fits all" solution is recommended here. Two aspects should be judged:

(1) whether or not the commodities that are reported in supplementary units are representing a significant fraction of total trade, (2) whether or not the effort to actually perform the conversions (including the availability of reliable conversion factors) is high. In this latter respect the decision between regional specific and average conversion factors is particularly important. The treatment of natural gas is a case in point and may serve as an illustration of the problematic.

#### Natural gas (SITC code 34, HS code 2705 and 2711): conversion to weight

The quantity of natural gas is commonly reported in volume units or calorific values. In principle, country specific data on calorific values and densities would be needed in order to convert reported volumes to metric tonnes. Such country specific coefficients are generally easier to obtain for the focal economy for which the MFA is compiled, than for those countries from which the natural gas is imported. In cases where the quantity of the imported natural gas is of minor relevance among the imported goods, it might be a disproportionately difficult task to investigate into country specific conversion factors for the imported natural gas. Instead, average conversion coefficients (such as those presented in table 20) can be used to convert natural gas volumes to mass units. For exported natural gas, national data on calorific values and densities can be applied for the conversion from volume to mass.

## **Compilation**

### **Allocation of foreign trade data to the MFA classification**

For the compilation of EW-MFA data from foreign trade statistics have to be allocated to the material groups listed in the MFA Tables (see table 21) according to their material composition. As far as possible, trade flows are allocated to material groups on the basis of their primary material component. The MFA classification system is different from any of the standard foreign trade classification systems in terms of groupings of materials and their allocation to a certain digit level. To facilitate an univocal allocation of data structured according to a standard foreign trade classification system to the MFA classification system correspondence tables between the MFA classification system and the most common international trade classification systems (SITC rev.3 and 4, CN) are included in MFA tables (see annex to MFA tables). It is assumed that correspondence tables between these classification systems and other national and international trade nomenclatures are easily available.

As can be seen from the correspondence tables in the annex, the level of disaggregation at which the foreign trade data are required depends on the type of products. Foreign trade

data can sometimes be integrated into MF accounts on the 2-digit level of trade classifications, but in some cases, data on much higher digit levels are required (see e.g. MFA category 1.3.1. which is an aggregate of five SITC rev.3 commodities at the 5-digit level).

In general, every group of traded goods, which is measurable in tonnes, is allocated to one MFA category. But conversely, not every MFA category has to be filled with trade data. A small number of material categories are not applicable to trade flows (e.g. 1.2.1.1 “straw”, 1.2.2.2 “grazed biomass”, 1.5 “hunting and gathering”). Additionally, it is possible that in some countries or years no commodities or goods of a specific material group are imported or exported.

In the trade tables some additional categories, which do not apply to DE, are included. This is the case for 1.6 “live animals, meat, and meat products” and for the categories in which products are subsumed such as 1.7, 2.3, 3.3, 4.3, and finally category 5 and 6.

It should be stressed that the allocation of foreign trade categories to the MFA categories is not unambiguous because the trade classifications always distinguish between different goods, whereas the MFA classification distinguishes between different types of materials. As goods are often a mixture of different materials no unequivocal correspondence between these two classification systems is possible.

Despite this conceptual incompatibility between MFA and trade classifications it is possible to determine for most goods the main material component (as e.g. for most biomass goods), or the main raw materials used in the production (as e.g. for steel ingots). For others, it is only possible to classify the good as either of biomass, mineral, or fossil fuel origin. In these latter cases, the commodities are assigned to additional material categories such as “products from biomass origin” (B.1.7). The remaining goods, mostly commodities that are highly processed and consist of a complex mix of materials, for which it is not possible to determine a main material component, are summarized in the category “other products” (B.5).

### **Adjustments for residence principle**

Additionally, adjustments to the residence principle can be made if the necessary information is available: It has been outlined in the “Fundamentals” section that economy wide material flow accounts follow the residence principle. Accordingly, EW-MFAs account for all material flows associated with transactions attributed to so-called resident units of a national economy. Generally speaking, the statistical data which are used to compile material flow accounts fully comply with the residence principle. In the case of foreign trade statistics, which follows a territorial approach, some adjustments are required. Above all this concerns flows associated with mobile resident units and in particular fuel used in international water,

air or land transport<sup>7</sup>: Fuel purchased by resident units outside the national economic territory and fuel purchased by non-resident units within the national economic territory are material flows not covered by foreign trade statistics but are regarded imports and exports, respectively, according to the residence principle. To accommodate the inconsistency between trade statistics and residence principle, items “B 4.2.3 Adjustment for residence principle: Fuel bunkered by resident units abroad” and “C 4.2.3 Adjustment for residence principle: Fuel bunkered by non-resident units domestically” have been introduced in the Tables B and C.

The data required for these adjustments are, however, not readily available. Data on fuel use in international transport is not systematically collected and published and up to date no standardized methods for data approximation exist. This also holds true of national accounts and their satellites, where similar adjustments are made. Some attempts to solve these problems have been made, for example, in Eurostat’s Manual for Air Emissions Accounts (Eurostat 2009a), which provides estimation procedures for the emissions related to fuel used by non-resident units domestically and resident units abroad. For EW-MFA standardized procedures are yet to be developed. Currently only recommendations can be made on how to quantify the flows accounted for under B and C 4.2.3 “Adjustment for residence principle”.

The relative size of the flows accounted for in item 4.2.3 can vary largely from country to country. Some of these flows can be negligible; others can be of considerable size. In particular in countries with large airport hubs or ports on the economic territory, significantly sized shipping fleets, or important transit routes, the amount of fuel bunkered by non-resident units domestically can be considerable and adjustments may be necessary. In general, an appraisal of amount of fuel used by resident units abroad is even more difficult than the quantification of flows associated with non-resident units domestically because no domestic statistical recordings are available.

In general three paths for obtaining the required information (or a combination of these paths) are potentially viable:

- 1) Energy and transport statistics: In some countries national energy or transport statistics collect data on fuel use in international transport. Experts in energy and

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<sup>7</sup> Other areas where adjustments would theoretically be necessary include e.g. food consumption of tourists or material flows related to activities of embassies or consulates (extraterritorial enclaves). As no statistical data or reliable estimation procedures exist, these flows are currently not considered in EW-MFA.

transport statistics should be consulted to support a first assessment of the significance of the concerned flows and to identify statistical sources.

- 2) National air emissions accounts (NAMEA-air): Like EW-MFA national air emissions accounts follow the residence principle and they report air emissions from international transport. So called “bridging items” reported in national air emissions accounts (Eurostat 2009a) provide data on emissions from national residents abroad and non-residents on the territory by transport type and can be used to calculate the corresponding fuel flows requested in EW-MFA. We suggest to use information on CO<sub>2</sub> emissions from national air emissions accounts and country-specific emission factors by fuel type and use (which are e.g. collected and reported by the IPCC in its *Emission Factor Data Base* (EFDB)) to calculate the mass of fuel flows.
- 3) National accounts: National accounts have a long tradition in dealing with practical difficulties resulting from a consequent implementation of the residence principle. In general, national accounts experts have a good overview on the required adjustments and monetary data on fuel use in international transport may be available from national accounts. On the basis of monetary data on fuel used by non-resident units domestically and fuel used by resident units abroad and corresponding fuel prices mass flows can be calculated.

## Data compilation and cross checks

With regard to foreign trade databases, a broad variety of software solutions exists and each requires an individual approach to the process of data acquisition. In the following descriptions, we will use the two international databases Comext and Comtrade as examples on how to compile physical foreign trade data.

Compilation of physical trade data begins with the definition of the data query, according to the aggregation level specified in the standard tables, followed by the download of the respective data in physical and monetary units. In case a database is used in which physical units are not displayed on higher aggregation levels, a medium aggregation level must be chosen on which the share of reported tonnes is sufficient. In the case of Comtrade, the 3-digit level of the SITC classification fulfils this requirement.

According to the correspondence tables in the Eurostat Standard Tables, each foreign trade flow can be allocated to an MFA category.

**Please note!** We recommend to carry out the download and the allocation to MFA categories for both physical and monetary data. The reason is that the monetary data represent valuable sources for cross-checks, described subsequently, as well as for additional data analysis.

In industrial economies trade volumes are known to be highly dynamic and characterized by relatively large fluctuations depending on a number of national and international economic factors. Consequently, time series data of physical and also monetary trade flows normally do not reveal smooth trends. Nonetheless, fluctuations in physical trade data compiled in material flow categories can also be the result of changes or flaws in the physical data reported. Reasons for this may be among the following:

- General problems in data reporting,
- Changes in trade classifications,
- Changes in the physical units reported,
- Changes in conventions of trade statistics (such as whether packaging material is included),
- Suppressed data due to reasons of confidentiality.

We therefore recommend carrying out visual assessment of the time series of the data on a medium aggregation level. If this step gives rise to doubt in any of the data, the following methods can be applied to check whether or not the data fluctuation is due to data flaws which have to be corrected.

Whenever fluctuations are detected that call for further investigation, i.e. fluctuation which are significantly larger as the average, the commodity group(s) responsible in particular should be identified on the next level of dis-aggregation. The monetary trade data and the calculated prices can be used in crosschecking. Where necessary, missing or false physical data in single years can be estimated by use of monetary trade flow data and tonne prices in adjacent years. Another possibility to cross-check or complete missing data is to refer to alternative data sources, e.g. national or international statistics on traded goods, for example the IEA or FAO.

## Table D: Domestic processed output (DPO)

The indicator Domestic Processed Output to nature (DPO) was developed and applied first by an international team of experts in a joint effort resulting in the publication “The Weight of Nations” (Matthews et al. 2000). DPO indicates the total weight of materials which are released back to the environment after having been have been used in the domestic economy. These flows occur at the processing, manufacturing, use, and final disposal stages of the economic production and consumption chain. Exported materials are not included in DPO because they are yet to be used in other countries.

DPO was calculated for the USA, Japan, Austria, Germany, The Netherlands (Matthews et al. 2000), for Finland (Muukkonen 2000), for the EU-15 (Bringezu and Schütz 2001), for the Czech Republic (Scasny et al. 2003) and for Italy (Barbiero et al. 2003). Table 22 shows DPO data around the year 2000 for some industrial economies.

**Table 22: Selected results for DPO**

tonnes per capita	Austria	Japan	Germany	Nether-lands	USA	Finland	Italy
	1996	1996	1996	1996	1996	1997	1997
Emissions to air	10.3	10.4	11.7	15.2	22.0	16.9	8.2
CO <sub>2</sub>	10.1	10.4	11.5	15.1	20.5	16.8	7.9
Waste landfilled	1.1	0.6	0.9	0.6	1.6	1.9	1.0
Municipal waste		0.10	0.15	0.5		0.4	0.4
Emissions to water	0.01	0.01	0.04	0.04	0.03	1.4	0.2
Dissipative use of products	1.1	0.10	0.6	2.4	0.5	4.2	2.5
Organic fertiliser	0.7	0.09	0.3	2.3	0.3	3.8	2.3
Dissipative losses	0.06		0.01		0.00		0.03
DPO not further defined					1.0	1.0	
<b>DPO</b>	<b>12.5</b>	<b>11.2</b>	<b>13.1</b>	<b>18.2</b>	<b>25.1</b>	<b>25.4</b>	<b>11.8</b>

Sources: Matthews et al. 2000: Austria, Japan, Germany, Netherlands, USA; Muukkonen 2000: Finland; Barbiero et al. 2003: Italy.

Note: at the time these studies were performed, DPO was defined including waste landfilled. In this Guide, waste to controlled landfills is excluded from DPO.

As can be clearly seen from table 22, emissions to air by far dominate the overall DPO level, and CO<sub>2</sub> emissions dominate the emissions to air. On average (measured as weighted

average across all countries shown in table 22), emissions to air accounted for 85% of DPO and CO<sub>2</sub> accounted for 94% of emissions to air.

The DPO account comprises 5 major categories:

D.1. Emissions to air

D.2. Waste landfilled (uncontrolled)

D.3. Emissions to water

D.4. Dissipative use of products

D.5. Dissipative losses

The first three categories (D.1. to D.3.) refer to the three gateways through which materials are initially released to the environment, i.e. air, land, and water, commonly referred to as emissions and waste in official statistics. The remaining two categories (D.4. and D.5.) are residual categories which are not fully attributable to a specific gateway but are rather attributed to a type of release, dissipative or deliberate, than to an environmental gateway.

Apparently there can be overlaps between a distinction according to gateways and a distinction according to dissipative uses and losses. Mainly these potential overlaps refer to a few emissions to air. Essentially there are two practical rules that help avoiding double counting between emissions to air and other categories of DPO:

1. N<sub>2</sub>O emissions from product use and NMVOC emissions by solvents are accounted for in “dissipative use of products” and not in “emissions to air”.
2. Emissions to air from fertiliser application, such as N<sub>2</sub>O and NH<sub>3</sub> are not accounted for in DPO. The related primary output is fertiliser spread on agricultural soil. The inclusion of these emissions thus would represent double counting.

**Please note!** So far no fully standardised methods for the compilation of DPO from different data sources have been developed and the quality, structure and comprehensiveness of available data sources differ largely across countries. It is therefore not possible to provide default procedures in sufficient detail. The following recommendations are of a more general nature and will inevitably leave some questions unanswered. It certainly will require the judgment and creativity of the practitioner to apply these general rules to the specific national situation. It is good practise to specify clearly the assumptions made and the data sources used, so that the issue of completeness can be evaluated. In particular this applies to the estimation of CO<sub>2</sub> emissions, as they by far dominate both DPO and emissions to air.

# Emissions to air

**Table 23: Domestic processed output: emissions to air**

1 digit	2 digit	3 digit
D.1 Emissions to air		
	D.1.1 Carbon dioxide (CO2)	
		D.1.1.1 Carbon dioxide (CO2) from biomass combustion
		D.1.1.2 Carbon dioxide (CO2) excluding biomass combustion
	D.1.2 Methane (CH4)	
	D.1.3 Dinitrogen oxide (N2O)	
	D.1.4 Nitrous oxides (NOx)	
	D.1.5 Hydroflourcarbons (HFCs)	
	D.1.6 Perflourocarbons (PFCs)	
	D.1.7 Sulfur hexaflouride	
	D.1.8 Carbon monoxide (CO)	
	D.1.9 Non-methane volatile organic compounds (NMVOC)	
	D.1.10 Sulfur dioxide (SO2)	
	D.1.11 Ammonia (NH3)	
	D.1.12 Heavy metals	
	D.1.13 Persistent organic pollutants POPs	
	D.1.14 Particles (e.g PM10, Dust)	

## Introduction

Emissions to air are gaseous or particulate materials released to the atmosphere from production or consumption processes in the economy. In MFA emissions to air comprise 14 main material categories on the 2digit level, as shown in the table 23.

## Data sources

Statistical reporting on air emissions has a relatively short history as compared to agricultural, mining or trade statistics. As a consequence data from different sources are less harmonized and gaps in the historical record are likely to occur. As a general rule in MFA it is recommend to use national data sources. The following section briefly describes three

important inventories for emissions to air that are based on national data, and subsequently compiled in international data bases.

1. **National greenhouse gas inventories in the common framework of IPCC:** The national inventories cover emissions to air that have a greenhouse gas potential, i.e. contribute directly and indirectly to global warming. Countries which signed the UN Framework Convention on Climate Change (UNFCCC) are requested to compile their national greenhouse gas inventories according to the respective IPCC (International Panel on Climate Change) guidelines, i.e. in the common reporting format (CRF). The latest revision of these guidelines was published in 2006 (IPCC 2006) and covers sources and sinks of the direct greenhouse gases CO<sub>2</sub> (carbon dioxide), CH<sub>4</sub> (methane), N<sub>2</sub>O (dinitrogen oxide), HFC (hydrofluorocarbons), PFC (perfluorocarbons) and SF<sub>6</sub> (sulphur hexafluoride) as well as the indirect greenhouse gases NO<sub>x</sub> (nitrogen oxides), NMVOC (non-methane volatile organic components), CO (carbon monoxide), and SO<sub>2</sub> (sulphur dioxide). Country specific data are available at UNFCCC (<http://unfccc.int/2860.php>).

**Please note!** IPCC resp. UNFCCC report data based on the territory principle, and if used as data source need to be converted to the residence principle, e.g. using “bridge tables” as described in the Eurostat Manual Air Emissions Accounts (Eurostat 2009a). General information on the implications of the residence principle for EW-MFA accounts and required adjustments can be found in the fundamentals chapter of this guide and the chapter dealing with imports and exports.

2. **CORINAIR (CORE INventory of AIR emissions):** Air emission data are also compiled under the UNECE convention on long range transboundary air pollutants (LRTAP). The focus of this convention is on classical air pollutants. For European countries air emission data for the LRTAP are collected in CORINAIR a project of the European Topic Centre on Air Emissions and the EEA. CORINAIR includes the pollutants CO, NH<sub>3</sub>, NMVOC, NO<sub>x</sub>, PM<sub>10</sub>, PM<sub>2.5</sub>, SO<sub>2</sub> and it provides cross references to the Integrated Pollution Prevention and Control (IPPC) coding formats. Data for European countries can be accessed via EEA (<http://www.eea.europa.eu>).

**Please note!** Like UNFCCC data, CORINAIR data are based on the territory principle, and if used as data source need to be converted to the residence principle.

3. **Air emission accounts (NAMEA - national accounting matrices including environmental accounts):** In NAMEA environmental information is compiled consistently with the way activities are represented in the supply and use framework of the national accounts. NAMEA air thus provides air emission data by economic

activity. In Europe NAMEA air data are compiled at the national level by statistical offices and collected by EUROSTAT (<http://epp.eurostat.ec.europa.eu>). As NAMEA is a framework linking emissions to the input-output framework of the national accounts, the data structure and the applied conventions are somewhat different from the traditional emission inventories as e.g. the CORINAIR and the IPCC statistics, to ensure the comparability of NAMEA to the input output framework.

**Please note!** NAMEA air emissions data are in line with the residence principle, and if available should be used as primary data source for EW-MFA. Please refer to the Eurostat Manual Air Emissions Accounts (2009).

The three accounting systems serve different purposes and therefore reveal differences in coverage and accounting conventions. Often a combination of data source will be necessary to fill in D1 in table D. The most important points to consider when using data from emission inventories for MFA are discussed in the next section.

## Conventions

**Terminology and classification:** The terminology for emissions to air follows international harmonised standards of IPCC, CORINAIR or NAMEA.

**System boundaries:** In defining the system boundary for emissions to air it is important to ensure that this definition for the output side is consistent with the definition for the input side and with the definition of societal stocks. As a general rule the category “emissions to air” indicates the total weight of materials which are released to the air by national resident units on the national economic territory and abroad. There are some **exceptions** to be taken into account:

- All emissions to air listed under E.2 (**output balancing items**) are not included in DPO.
- **Emissions from fertilizer applications** are not included in DPO, as this would represent double counting with “dissipative uses”.
- **N<sub>2</sub>O emissions from product use and NMVOC emissions by solvents** are accounted for in “dissipative use of products” and not in “emissions to air”.
- Emissions from fuel for use on ships or aircraft engaged in international transport are called **international bunkers**. The quantity of these emissions, predominantly consisting of CO<sub>2</sub> from fossil fuel combustion, may be negligible for some countries and very significant for others. These emissions should be included in DPO. A note containing a clear description of the used data sources and applied assumptions is instrumental here.

**Please note!** The MFA system boundary is not necessarily identical with the system boundaries applied in the above mentioned emission inventories. There are several points to consider when using emissions inventories.

- IPCC and CORINAIR inventories are based on the territory principle and account for anthropogenic emissions from the economic territory, whereas NAMEA accounts for economic activities of residents, regardless whether they are active on the national economic territory or abroad (i.e. applying the residence principle; NAMEA also includes CO<sub>2</sub> emissions from international bunkers). If IPCC and/or CORINAIR data are used, adjustment to ensure consistency with the residence principle are required. For these adjustments data reported in the “bridge tables” of air emissions accounts (cf. Eurostat’s (2009a) *Manual Air Emissions Accounts*) can be used for these adjustments. In general, it is recommended to use NAMEA air emissions accounts as primary data source for all relevant emissions of greenhouse gases and air pollutants.
- IPCC reports usually totals GWP (global warming potential) measured in CO<sub>2</sub> equivalents and not in metric tonnes. In addition, the totals reported in the national greenhouse gas inventories are calculated according to a complex set of rules, specifying the recognition of sinks and the inclusion or exclusion of certain emissions. It is therefore necessary to use the underlying inventories rather than the totals for compiling emissions to air. It is also advisable to refer to the methodological guidelines (IPCC 2006) in order to check what is included or not in the data. IPCC recommends reporting emissions from international bunkers separately and not as part of the totals.

**Estimations:** Estimations are necessary if data are not available in tonnes or if emissions have to be estimated directly from input data by using coefficients. Estimations might also be necessary for longer time series. In rare cases emission data are reported without oxygen content (e.g. as carbon instead of CO<sub>2</sub>); they have to be converted using stoichiometric equations. In this guide we do not describe any estimation procedures for emissions to air. However, some important stoichiometric equations are reported in the chapter on balancing items. Should estimations become necessary, please refer to the Eurostat Manual Air Emissions Accounts (Eurostat 2009a).

**Oxygen content:** Oxygen is drawn from the atmosphere during fossil fuel combustion and other industrial processes. Overall, the amount of oxygen uptake from the atmosphere during production and consumption is quite substantial and accounts for approximately 20% by weight of material inputs to industrial economies (Matthews et al. 2000). In MFA, this atmospheric oxygen is not included in the totals on the input side (DE, DMC, and DMI) but it is included in the totals on the output side (DPO). The reason is that oxygen is a constituent

part of the pollutants and greenhouse gases, and that these emissions are usually reported and analysed with their oxygen content. To arrive at a full mass balance, the missing oxygen on the input side is reported as input balance items (see chapter on table E).

## Data compilation

### D.1.1 Carbon dioxide (CO<sub>2</sub>)

Carbon dioxide is a naturally occurring gas. It is a constituent part of the atmosphere and plays a decisive role for the metabolism of all living species. CO<sub>2</sub> serves as a nutrient for plants and is a metabolic residual for animals. Thus plant and animal metabolisms together constitute a dynamic equilibrium that is able to keep CO<sub>2</sub> concentrations in the atmosphere within a narrow range. The industrial metabolism, mainly by combusting huge amounts of fossil fuels, entails enormous net releases of CO<sub>2</sub> into the atmosphere. This CO<sub>2</sub> is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance. It is the reference gas against which other greenhouse gases are measured and therefore has a Global Warming Potential of 1.

**Please note!** CO<sub>2</sub> represented 77% of the global warming potential of all greenhouse gas emissions in 2004 (IPCC 2007), and it constituted some 90% of the weight of all emissions to air in industrial economies in the late 1990ies (Matthews et al. 2000). Apparently CO<sub>2</sub> is not only the most important part of DPO in terms of policy relevance. CO<sub>2</sub> also dominates the quantity of overall DPO: It is therefore good practise to concentrate most of the effort on the CO<sub>2</sub> account. Provided careful consideration of the applied system boundaries in each case, inventory data from NAMEA air emissions should be used. To assure correct accounting, it may be advisable to consult a national expert.

#### D.1.1.1 Carbon dioxide (CO<sub>2</sub>) from biomass combustion

This subcategory includes:

- Biofuels like biodiesel and bioethanol,
- biogas (which may be used both as a biofuel and as a fuel for producing electricity and heat),
- biomass for electricity and heat, mainly wood and agricultural harvest residuals,
- biomass used in rural areas of developing countries, especially fire wood and residuals or wastes from agriculture and forestry, also referred to as traditional biomass (REN21 2005).
- **Please note!** This category **does not include**

- CO<sub>2</sub> emissions from land use and land use changes: These flows cannot be accounted for with an input side equivalent. Instead, they are considered flows within the environment.
- CO<sub>2</sub> emissions from human or animal respiration, they are considered as output balancing items (see chapter G).

#### **D.1.1.2 Carbon dioxide (CO<sub>2</sub>) excluding biomass combustion**

This category includes CO<sub>2</sub> emissions from both energetic and non-energetic non-biotic sources.

**Please note!** CO<sub>2</sub> emissions from **international bunkers** should be included under D.1.1.2. These emissions may be estimated following the guidelines of IPCC (2006). The applied assumptions and data sources used should be described in a footnote.

#### **D.1.2 Methane (CH<sub>4</sub>)**

Methane, a hydrocarbon, is a greenhouse gas produced through anaerobic (without oxygen) decomposition of waste in landfills, animal digestion, decomposition of animal wastes, production and distribution of natural gas and oil, coal production, and incomplete fossil-fuel combustion.

**Please note!** Make sure that methane emissions from uncontrolled landfills are not included in the “emissions to air” total. They may be reported as a separate memorandum item.

#### **D.1.3 Dinitrogen monoxide (N<sub>2</sub>O)**

Dinitrogen monoxide (nitrous oxide) is a colourless non-flammable gas, with a pleasant, slightly-sweet odour. It is used in surgery and dentistry for its anaesthetic and analgesic effects, where it is commonly known as laughing gas due to the euphoric effects of inhaling it. It is also used as an oxidizer in internal combustion engines. N<sub>2</sub>O acts as a powerful greenhouse gas.

**Please note!** Make sure **not to include**:

- N<sub>2</sub>O emissions from product use which should instead be allocated to "dissipative use of products", and
- N<sub>2</sub>O emissions from agriculture and from wastes to uncontrolled landfills.

#### **D.1.4 Mono-nitrogen oxides (NO<sub>x</sub>)**

The two mono-nitrogen oxides are nitrogen dioxide (NO<sub>2</sub>) and nitric oxide (NO). NO<sub>2</sub> is an orange/brown gas and has a characteristic sharp, biting odour. NO<sub>2</sub> is one of the most prominent air pollutants and a respiratory poison.

#### **D.1.5. Hydrofluorocarbons (HFCs)**

HFCs are commercially produced gases used as a substitute for chlorofluorocarbons. HFCs largely are used in refrigeration and semiconductor manufacturing.

#### **D.1.6. Perfluorocarbons (PFCs)**

PFCs are by-products of aluminium smelting and uranium enrichment. They also replace chlorofluorocarbons in manufacturing semiconductors.

#### **D.1.7. Sulfur hexafluoride**

Sulfur hexafluoride is largely used in heavy industry to insulate high voltage equipment and to assist in the manufacturing of cable-cooling systems.

#### **D.1.8. Carbon monoxide (CO)**

CO is a colourless, odourless, and tasteless toxic gas. It is the product of the incomplete combustion of carbon-containing compounds, notably in internal-combustion engines. It still has significant fuel value, burning in air with a characteristic blue flame, producing carbon dioxide. CO is valuable in modern technology, being a precursor to myriad products.

#### **D.1.9. Non-methane volatile organic compounds (NMVOC)**

NMVOC is the abbreviation for non-methane volatile organic compounds. They easily vaporise at room temperature and most of them have no colour or smell. **Please note!** NMVOC emissions of solvents are included in "dissipative use of products" and not in "emissions to air".

#### **D.1.10. Sulfur dioxide (SO<sub>2</sub>)**

Sulphur dioxide is a colourless gas with a penetrating, choking odour. It dissolves readily in water to form an acidic solution (sulphurous acid) and is about 2.5 times heavier than air.

#### **D.1.11. Ammonia (NH<sub>3</sub>)**

In its pure state and under usual environmental conditions, ammonia exists as a colourless, pungent-smelling gas. It is alkaline, caustic and an irritant. Under high pressure, ammonia

can be stored as a liquid. It is highly soluble in water. It reacts with acids to form ammonium salts.

**Please note!** Ammonia emissions from agriculture are not included in “emissions to air”.

#### **D.1.12. Heavy metals**

There are several different definitions of which elements fall in this group: According to one definition, heavy metals are a group of elements between copper and bismuth on the periodic table of the elements having specific gravities greater than 4.0. All of the more well-known elements with the exception of bismuth and gold are toxic.

#### **D.1.13. Persistent organic pollutants (POPs)**

Persistent organic pollutants (POPs) are organic compounds that are resistant to environmental degradation through chemical, biological, and photolytic processes. Because of this, they have been observed to persist in the environment, to be capable of long-range transport, bio-accumulate in human and animal tissue, bio-magnify in food chains, and to have potential significant impacts on human health and the environment.

In May 1995, the UNEP Governing Council (GC) decided to begin investigating POPs, initially beginning with a short list of twelve POPs, which has been extended since then. The groups of compounds that make up POPs are also classed as PBTs (Persistent, Bioaccumulative, and Toxic) or TOMP (Toxic Organic Micro Pollutants).

#### **D.1.14. Particulates (e.g. PM10, Dust)**

PM10 are particles that vary in size and shape, have a diameter of up to 10 micrometers and are made up of a complex mixture of many different species including soot (carbon), sulphate particles, metals, and inorganic salts such as sea salt.

### **Waste landfilled**

#### **Introduction**

By definition, waste refers to materials that are not prime products (i.e. products produced for the market) and which are of no further use to the generator for purpose of production, transformation or consumption. The generator discards, intends or is required to discard these materials. Wastes may be generated during the extraction of raw materials, during the processing of raw materials to intermediate and final products, during the consumption of final products, and in the context of other activities.

The MFA table distinguishes between municipal and industrial waste and accounts for both of these only if they are discharged to uncontrolled landfills (see table 24):

**Table 24: Domestic processed output: waste landfilled**

1 digit	2 digit	3 digit
D.2 Waste land filled (uncontrolled)		
	D.2.1 municipal waste (uncontrolled)	
	D.2.2 industrial waste (uncontrolled)	

A landfill is defined as a deposit of waste into or onto land, both in the form of a specially engineered landfill and of temporary storage for over one year on a disposal site. These may be either internal (i.e. the waste is generated and disposed at the same site) or external (Eurostat 2005).

A controlled landfill is one whose operation is subject to a permit system and to technical control procedures in accordance with the national legislation in force. The sites of controlled landfills are specifically modified and maintained for this purpose. For the purposes of MFA, only waste disposed of outside of these controlled sites should be accounted for. This refers to so-called “wild” dumping which should be reported under D.2 if data available.

The following flows are excluded:

- Residuals directly recycled or reused at the place of generation.
- Waste materials that are directly discharged into ambient water or air. They are accounted for in emissions to air or water respectively.
- Waste that was generated by unused extraction. This refers mainly to soil excavation in constructions and to overburden from mining and quarrying.
- Waste incinerated. This flow is already accounted for in emissions to air.

### **Data sources**

First and foremost, national waste statistics should be used to acquire data for waste to uncontrolled landfills.

A recent overview on waste statistics data for European countries can be found in the Eurostat 2005 publication “Waste generated and treated in Europe – Data 1995-2003”. This report provides data for municipal waste landfilled with good coverage with respect to both

countries and time (1995 to 2003). Data for industrial waste landfilled are still scarce. In some sources the amounts of waste disposed in controlled landfills are shown separately from the total amounts landfilled, so that the difference can be taken for the amounts disposed in uncontrolled landfills.

The distinction between waste that goes to controlled and uncontrolled landfills, however, may be difficult and may require consultation of national experts.

## **Conventions**

**System boundaries:** There are two important system boundaries to be considered when accounting for waste as part of DPO. Only waste deposited in **uncontrolled** landfills (wild dumping) is an output to nature and therefore part of DPO. Consequently, emissions from uncontrolled landfills are not considered as this would constitute double counting.

In contrast, **controlled**, i.e. maintained, landfills must be considered part of the socio-economic system. Therefore, wastes deposited in controlled landfills should be accounted for as an addition to stock.

While this distinction is accepted on conceptual grounds, the Eurostat MFA task force admitted that it might be difficult to separate controlled from uncontrolled land fill in practical terms. In addition, the direct application of this argument to other areas of material flow accounting would imply changing the definitions of DPO and NAS. We therefore recommend to show the net material additions to controlled landfills as a memorandum item and to exclude them from the indicator NAS.

**Estimations:** Estimations may become necessary for industrial wastes landfilled (see Data Compilation).

**Water content:** Wastes are commonly reported in wet weight (including water content). If this waste flow is of substantial quantity, an attempt should be made to additionally provide the dry matter value (EC 2002).

## **Data compilation**

Waste statistics or other sources may report the total amounts of waste to uncontrolled landfills directly. If this is the case, these figures for waste landfilled should be taken as totals for the accounting of D.2 without further distinction between municipal waste and industrial waste. If this is the case, this information should be included in a footnote.

The current status of European data is described in Eurostat (2005). There, data for waste landfilled are provided only for non-hazardous waste from the manufacturing industry, and only sporadically for countries and years. Data for waste landfilled from energy production

and water supply, from the construction sector, from agriculture, forestry and fishery, from mining and quarrying, and from the service and public sector are not included at all.

It may therefore be necessary to perform estimations if national sources do not provide better data. These estimates could concentrate on the two main positions, waste landfilled from the manufacturing industry and waste landfilled from construction.

Waste landfilled from the manufacturing industry is reported for some European countries and years by Eurostat (2005). Using data for the gross value added in the same year by the manufacturing industry, the amount of waste landfilled per unit GVA can be derived (in tonnes waste per Euro gross value added). Then, the amount of waste landfilled can be estimated by multiplying the tonnes of waste per Euro GVA with the total amount of gross value added by the manufacturing industry in a given year.

The estimate for waste landfilled from construction (construction and demolition waste excluding excavated soil – see below) can be performed in a similar way. Eurostat, however, does not provide data for construction waste landfilled so far. These data have to be derived from specific national sources. A respective database should be established.

**Please note!** Only waste to uncontrolled landfills should be counted under D.2. If no specific data are available, national experts should be consulted. If no reliable information can be found on waste discharged to uncontrolled landfills, for industrialized economies, the assumption can be made that only controlled landfills are used.

Construction and demolition waste includes rubble and other waste material arising from the construction, demolition, renovation or reconstruction of buildings or parts thereof, whether on the surface or underground. It consists mainly of building material and soil, including excavated soil. It includes waste from all origins and from all sectors of economic activity. For the requirements of economy-wide MFA, excavated soil has to be omitted from the figures for construction and demolition waste. Excavated soil or earth represents a material flow of the unused domestic extraction type which is not part of the direct material inputs to the economy and must therefore also be excluded from the domestic processed output of the economy.

# Emissions to water

## Introduction

Emissions to water are substances and materials released to natural waters by human activities after or without passing waste water treatment. Accounting for only 1%, emissions to water represent the smallest category of DPO (Matthews et al. 2000). In the context of a full material balance of a national economy it is therefore sufficient to roughly estimate emissions to water.

**Table 25: Domestic processed output: emissions to water**

1 digit	2 digit	3 digit
D.3	Emissions to water	
	D.3.1	Nitrogen (N)
	D.3.2	Phosphorus (P)
	D.3.3	Heavy metals
	D.3.4	Other substances and (organic) materials
	D.3.5	Dumping of materials at sea

## Data sources

NAMEA-water, emission inventories, and environmental reports are the main data sources for emissions to water. It should be noted that statistics on water pollution commonly use a specific reporting terminology. While the inorganic pollutants nitrogen and phosphorus as well as heavy metals are commonly reported as elements, organic pollutants are reported as compounds by using various indirect aggregate indicators. Due to the minor quantitative importance of emissions to water in the overall material flow accounts, the estimation of specific balancing items is not necessary.

## Conventions

**Terminology and classification:** The MFA classification for emissions to water represents an aggregation of the main categories reported in the emissions statistics.

## **System boundaries**

Emissions to water are materials which cross the boundary from the economy back into the environment with water as a gateway. Therefore, emissions to water should be accounted for at the state they are in upon discharge to the environment. Where waste water treatment occurs, this refers to the post-treatment state. Otherwise, it refers to the substances or materials directly released to the environment via water. It should be noted that statistics on water pollutants traditionally focused on the concentration of the pollutants in the water bodies. Attention must therefore be paid to including only data on *flows* of pollutants into the water bodies (normally measured in quantity per year) and not data on pollutant *concentration* in the water bodies (normally measured in quantity per volume).

## **Data compilation**

### **D.3.1 Nitrogen (N)**

Total nitrogen (N) stands for the sum of all nitrogen compounds. Nitrogen from agriculture is not included in the category emissions to water because it is already included in the category “dissipative use of products” as nitrogenous fertilisers. N-emissions to water include emissions by waste water from households and industry.

### **D.3.2 Phosphorus (P)**

As with nitrogen, total phosphorus (P) stands for the sum of all phosphorus compounds. P-emissions to water include emissions by waste water from households and industry and do not include emissions from agriculture, as these are again included in category “dissipative use of products” as phosphorus fertilisers.

### **D.3.3 Heavy metals**

Heavy metals may come from municipal and industrial discharges. For example, for Germany the share of municipal emissions in total discharge of heavy metals is 77 % on average (between 62 % for lead and almost 93 % for mercury). The most important industrial source is the chemical industry with 40 % of the total industrial discharge (Böhm et al. 2000).

### **D.3.4 Other substances and (organic) materials**

Organic substances are commonly reported in water emission inventories as indirect summary indicators. The most commonly used are BOD (biological oxygen demand), COD (chemical oxygen demand), TOC (total organic carbon), or AOX (adsorbable organic halogen compounds). **Please note!** All of these indicators measure organic substances in water by each using a different indirect method. The values reported for these indicators should

therefore neither be included directly in MFA nor should they be aggregated. It is necessary to:

(1) Make a decision as to which of the indicators to use. Our recommendation is to take TOC, if available, as it is the most comprehensive and sensitive indicator.

(2) Convert the reported quantity which indirectly indicates the amount of organic substances into the quantity of the organic substance itself by using a simplified stoichiometric equation.

### D.3.5 Dumping of materials at sea

Dumping of materials at sea is not a common reporting format. If data are not available, this category may simply be left blank. **Please note!** Attention should be paid not to include materials which are part of the unused domestic extraction, like dredging, in order to be consistent with the material input side.

## Dissipative use of products

### Introduction

“Some materials are deliberately dissipated into the environment because dispersal is an inherent quality of product use or quality and cannot be avoided” (Matthews et al. 2000, p 27). Examples of dissipative use flows are inorganic and organic fertilizers such as manure, compost, or sewage sludge.

**Table 26: Domestic processed output: dissipative use of products**

1 digit	2 digit	3 digit
D.4	Dissipative use of products	
	D.4.1	Organic fertiliser (manure)
	D.4.2	Mineral fertiliser
	D.4.3	Sewage sludge
	D.4.4	Compost
	D.4.5	Pesticides
	D.4.6	Seeds
	D.4.7	Salt and other thawing materials spread on roads (incl grit)
	D.4.8	Solvents, laughing gas and other

Matthews et al. (2000) were the first to make an attempt to account for these flows as part of an MFA. Their results for 1996 show, for example, that applied mineral fertiliser ranged from 17 kilogram per capita and year in Japan to around 110 kg/cap in Austria and Germany, spread manure from 105 kg/cap in Japan to 2282 kg/cap in the Netherlands, sewage sludge from 4 kg/cap in the Netherlands to 13 kg/cap in Germany, pesticides from 0.4 kg/cap in Germany to 3 kg/cap in Austria, and grit materials from 26 kg/cap in Germany to 134 kg/cap in Austria.

## **Data sources**

Data on dissipative use of products are rarely reported in official statistics. Data on the consumption and use of mineral fertiliser, pesticides, or seeds may be found in agricultural statistics. Data for organic fertiliser usually have to be estimated. Data for sewage sludge, compost, and salt and other thawing materials on roads may be reported in statistics or reports on the environment or in specific studies. National air emission inventories commonly include data for emissions from the use of solvents and N<sub>2</sub>O as a product.

## **Conventions**

**Water content:** Organic fertiliser (manure) spread on agricultural land should be reported in dry weight. If reported with water content, an attempt should be made to convert the data to dry matter. The same holds true for sewage sludge and compost.

## **Data compilation**

### **D.4.1 Organic fertiliser (manure)**

Manure is organic matter, excreted by animals, which is used as a soil amendment and fertilizer.

Manure spread on agricultural land is usually not or not sufficiently reported in agricultural statistics and has to be estimated (see e.g. Matthews et al. 2000). An estimate could be based on the number of livestock by type multiplied with the manure production per animal per year and a coefficient to correct for dry matter. Examples for required coefficients are given in table 27.

**Table 27: Daily manure production coefficients**

	Manure production per animal per day in kg	Dry matter of manure 1= Wet weight
Dairy cows	70	0.085
Calves	17	0.05
Other bovine	28	0.085
Pigs for slaughtering	7	0.071
Pigs for breeding	26	0.028
Other pigs	8	0.071
Sheep	7	0.07
Horses	7	0.07
Poultry	0.2	0.15

Source: Meissner 1994

#### **D.4.2 Mineral fertiliser**

The fertiliser industry is essentially concerned with the provision of three major plant nutrients - nitrogen, phosphorus and potassium - in plant-available forms. Nitrogen is expressed in the elemental form, N, but phosphorus and potassium may be expressed either as the oxide ( $P_2O_5$ ,  $K_2O$ ) or as the element (P, K). Sulphur is also supplied in large amounts, partly through the sulphates present in such products as superphosphate and ammonium sulphate.

Accordingly, agricultural statistics commonly report domestic consumption in agriculture of specified nitrogenous fertilizers, phosphate fertilizers, and potash fertilizers, and multi-nutrient fertilizers (NP/NPK/NK/PK). FAOSTAT e.g. reports nitrogenous fertilizers, phosphate fertilizers, and potash fertilizers for the EU. Data mostly refer to nutrient content of fertilisers. A fertiliser often not reported is lime (e.g. in forestry) for which specific sources should be checked.

In principle, the accounting of fertilisers and pesticides would have to be for the total masses. Statistics, however, commonly report fertilisers in nutrient contents (e.g. N,P,K) and pesticides in active ingredients contents. In case multipliers to total weight are known, the account should be based on total weights.

#### **D.4.3 Sewage sludge**

Sewage sludge refers to any solid, semi-solid, or liquid residue removed during the treatment of municipal waste water or domestic sewage. Although it is useful as a fertiliser and soil conditioner, sewage sludge, if applied inappropriately can also be potentially harmful to the

water and soil environment and human and animal health. The application of sludge on agricultural land is therefore subject to strict regulations in many countries.

Sewage sludge spread on agricultural land may be reported in environment statistics or in specific studies. Sewage sludge should be reported in dry weight. If reported in wet weight, a water content of 85% may be assumed for conversion to dry weight.

#### **D.4.4 Compost**

Composting refers to a solid waste management technique that uses natural processes to convert organic materials to humus through the action of microorganisms. Compost is a mixture that consists largely of decayed organic matter and is used for fertilizing and conditioning land.

Compost may be reported in agricultural statistics, in environment statistics, or in specific studies. Compost should be reported in dry weight. If reported in wet weight, a water content of 50% may be assumed for conversion to dry weight.

#### **D.4.5 Pesticides**

A pesticide is commonly defined as "any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest". A pesticide may be a chemical substance or biological agent (such as a virus or bacteria) used against pests including insects, plant pathogens, weeds, molluscs, birds, mammals, fish, nematodes (roundworms), and microbes. Pesticides are usually, but not always, poisonous to humans. An extensive list and data of pesticides is provided in the PAN Pesticides Database ([http://www.pesticideinfo.org/List\\_ChemicalsAlpha.jsp](http://www.pesticideinfo.org/List_ChemicalsAlpha.jsp)).

Agricultural statistics commonly report quantities of pesticides used in (or sold to) the agricultural sector. Figures are generally expressed in terms of active ingredients. If multipliers are available, these figure should be converted to total mass.

#### **D.4.6 Seeds**

Seeds are the encapsulated embryos of flowering plants. Seeds for agricultural production are a common position in agricultural statistics (e.g. from FAO food commodity balance sheets).

#### **D.4.7 Salt and other thawing materials spread on roads (incl. grit)**

First estimations for these flows were carried out for Austria and the U.S. (Matthews et al. 2000). In Germany, for example, the use of salt on roads is recorded on the level of

municipalities and reported nation-wide in specific studies. If data are not available, this position may be neglected.

#### **D.4.8 Solvents, laughing gas and others**

This category includes emissions from use of solvents (in particular NMVOC) and N<sub>2</sub>O as a product (for anaesthesia).

Data for NMVOC solvents emissions can e.g. be taken from national inventory reports to UNFCCC from the CRF reporting categories:

3.A Paint application

3.B Degreasing & dry cleaning

3.C Chemical products manufacture & processing

3.D Other

N<sub>2</sub>O (laughing gas) for anaesthesia is included in 3.D and its specific values may be extracted from detailed countries' air emissions databases.

#### **Specific issues related to dissipative use of products**

**Manure produced versus manure spread on fields:** Not all manure produced is actually spread on agricultural land. A part is lost from the economic system as emissions to water. The ISTAT estimated this loss at 5% (Barbiero et al. 2003) and reported it under emissions to water. Furthermore, manure loses some of its weight during stockpiling due to emissions to air (nitrogen compounds, methane and NMVOC, partly by combination with atmospheric gases). The DPO account may be corrected for these air emission losses from manure if information is available or a feasible estimation procedure has become available.

**Compost in private households:** Households may compost organic materials previously purchased (i.e., biomass that was recorded on the input side). Such composting is usually not recorded in statistics. If relevant for this DPO category, an estimate would have to be added on the output side.

# Dissipative losses

## Introduction

Dissipative losses are unintentional outputs of materials to the environment resulting from abrasion, corrosion, and erosion at mobile and stationary sources, and from leakages or from accidents during the transport of goods.

There are only very few data available internationally. Matthew et al. (2000) report estimated data for the abrasion from tires for Austria, Germany and USA.

**Table 28: Domestic processed output: dissipative losses**

1 digit	2 digit	3 digit
D.5. Dissipative losses (e.g abrasion from tires, friction products, buildings and infrastructure)		

### D.5. Abrasion from tires, friction products, buildings and infrastructures and others

This category includes various types of dissipative flows. Many of them have never been quantified. It is recommended to fill in only those data that can be provided with a justifiable effort.

- Abrasion from tires is rubber worn away from car tires. The procedure applied in the Austrian case study in Matthews et al. (2000) used data from transport statistics together with a coefficient of 0.03 g/km for the average abrasion per tire, taken from a special study on ecology and road traffic in Austria.
- Particles worn from friction products, such as brakes and clutches, so far have never been addressed in MFA.
- Losses of materials due to corrosion, abrasion, and erosion of buildings and infrastructure are probably a quantitatively relevant position, and they appear to be relevant under environmental aspects as well. So far, there is no comprehensive approach to account of these flows. Single aspects like losses due to leachate of copper from roofing or paints from construction have been studied, though. Such studies may serve as a starting point towards more comprehensive accounts of material losses of this kind.

- Dissipative losses may also result from the transport of goods. In German statistics, for example, the amount of chemicals irreversibly lost due to accidents during transport is reported.
- Another position may be leakages during (natural) gas pipeline transport (if not reported as emissions to air). Data may be reported in specific studies.

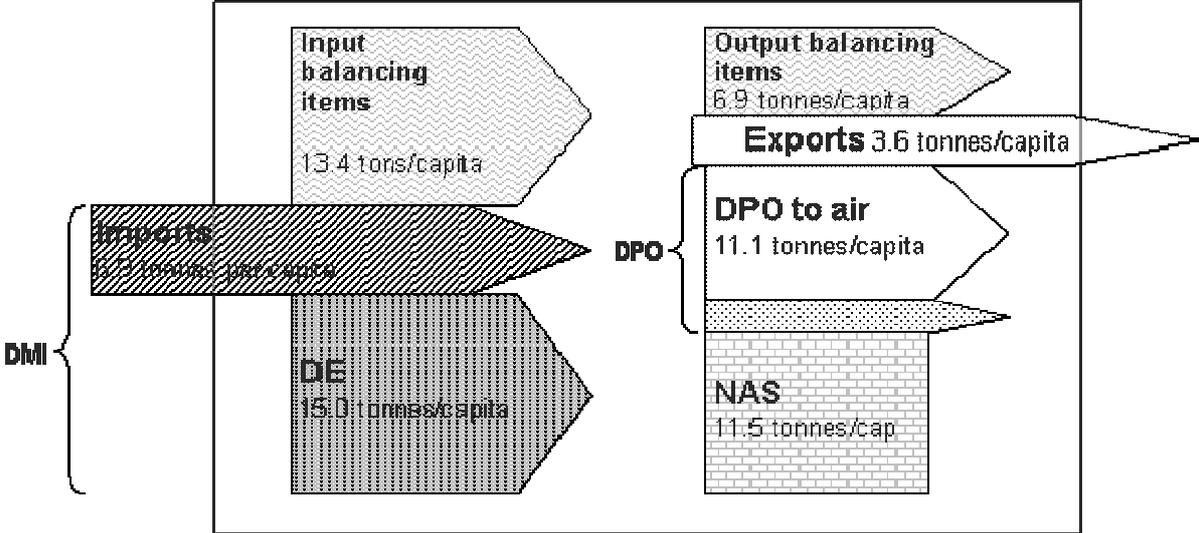
# Table E: Balancing items and net additions to stock

## Introduction

Some material inputs and material outputs which are part of DMI and DPO are not sufficiently counterbalanced on the respective opposite side of the material balance. For example, carbon contained in an energy carrier is combusted and the CO<sub>2</sub> is counted on the output side. This requires adding the O<sub>2</sub> on the input side to arrive at a correct balance. Or, energy carriers on the material input side contain water which is released through combustion as water vapour on the output side and needs to be added there as a balancing item.

These additional inputs and outputs that are needed to compile a full mass balance are significant mass flows, as can be seen from Figure 3. In MFA they are called balancing items. They are reported in specific tables and are not included in the aggregate indicators. A comprehensive and accurate estimation of balancing items is instrumental when the indicator NAS (net additions to stock) is calculated as the difference between total inputs and total outputs.

Figure 3: Balancing inputs with outputs: Austria 1996



Source: Institute for Social Ecology data base

## Balancing items: Input side (gases and water)

### Introduction

Balancing items on the input side account for those flows of water and air that are accounted for in DPO but not in DE or imports. The main processes concerned are combustion of fuels, respiration of humans and livestock, and the production of ammonia via the Haber-Bosch process. **Please note:** Also water requirements for the domestic production of exported beverages may be a relevant balancing item for the input side in some countries. The amount of water withdrawn from the domestic territory may be estimated based on export data. However, so far no reliable method has been reported for this item. Compilers are encouraged to contribute their experience with this issue to the further development of adequate methods.

### Data compilation

#### E.1.1 Oxygen for combustion processes

Step 1: Oxygen for combustion processes can be calculated stoichiometrically from respective data for emissions of CO<sub>2</sub>, CO, SO<sub>2</sub>, N<sub>2</sub>O and NO<sub>2</sub> from combustion:

$C + O_2 \rightarrow CO_2$ , i.e.  $12 + 32 = 44$ , and  $\approx 0.727$  oxygen per CO<sub>2</sub>

$C + O \rightarrow CO$ , i.e.  $12 + 16 = 28$ , and  $\approx 0.571$  oxygen per CO

$S + O_2 \rightarrow SO_2$ , i.e.  $32 + 32 = 64$ , and  $\approx 0.5$  oxygen per SO<sub>2</sub>

$2N + O \rightarrow N_2O$ , i.e.  $28 + 16 = 44$ , and  $\approx 0.364$  oxygen per N<sub>2</sub>O

$N + O_2 \rightarrow NO_2$ , i.e.  $14 + 32 = 46$ , and  $\approx 0.696$  oxygen per NO<sub>2</sub>

The required data for emissions from combustion should be taken from the DPO account. They are multiplied with the above factors for oxygen per substance emitted to obtain oxygen for combustion processes.

Step 2: In addition, oxygen is required for combustion of the hydrogen (H) contents of energy carriers, with the resulting emission being water vapour (H<sub>2</sub>O):

$2H + O \rightarrow H_2O$ , i.e.  $2 + 16 = 18$ , and  $\approx 0.889$  oxygen per H<sub>2</sub>O from H.

For this, hydrogen contents of energy carriers combusted and the resulting emissions of water vapour have to be determined. Table 29 provides exemplary values from German emission inventories for the respective oxygen demand.

**Step 3:** Total oxygen for combustion is finally calculated as the sum of the amount calculated in step 1 (related to emissions of CO<sub>2</sub>, CO, SO<sub>2</sub>, N<sub>2</sub>O and NO<sub>2</sub>) and step 2 (H<sub>2</sub>O from H).

**Table 29: Oxygen demand for oxidation of H compound of energy carriers to H<sub>2</sub>O**

<b>Energy carrier</b>	<b>Oxygen in t per t energy carrier</b>
Sewage gas/ Biogas/ Landfill gas	1.57
Hard coal	0.37
Coke (hard coal)	0.06
Hard coal briquettes	0.33
Brown coal, crude	0.15
Dust- and dry coal	0.33
Hard brown coal	0.32
Brown coal briquettes and -coke	0.33
Mine gas	1.57
Coke oven gas	1.57
Natural gas, Crude oil gas	1.83
Gasoline	1.14
Diesel	1.06
Aviation gasoline	1.19
Fuel oil, light	1.07
Fuel oil, medium and heavy	0.93
Liquid gas	1.41
Refinery gas	1.71
Other solid fuels	0.40
Blast furnace gas	0.02

Source: derived from Frischknecht et al. 1994, Kugeler et al. 1990, Osteroth, 1989.

### E.1.2 Oxygen for respiration (of humans and livestock)

Oxygen for respiration can be calculated using standard coefficients based on population numbers and livestock numbers (see table 30).

**Table 308: Metabolic oxygen demand of humans and livestock**

Oxygen demand for respiration	t O <sub>2</sub> per capita resp. head and per year
Humans	0.25
Cattle	2.45
Sheep	0.20
Horses	1.84
Pigs	0.25
Poultry	0.01

Source: Wuppertal Institute data base, based on Matthews et al. 2000.

### E.1.3 Nitrogen for Haber-Bosch process

The Haber-Bosch process designates the reaction of nitrogen and hydrogen to produce ammonia. Nitrogen is obtained from the air, and hydrogen is obtained from water and natural gas in steam reforming. Via this process around 500 million tonnes of artificial fertilizer are produced every year, mostly in the form of anhydrous ammonia, ammonium nitrate, and urea. Fertilizer produced in the Haber-Bosch process is responsible for sustaining 40% of the Earth's population. Roughly 1% of the world's energy supply is consumed in the manufacturing of this fertilizer (Smith 2002).

The nitrogen (N) and hydrogen (H) are reacted over an iron catalyst (Fe) under conditions of 250 atmospheres (atm) and 450-500 °C:



(Where  $\Delta H$  is the heat of reaction or enthalpy. For the Haber process, this is -92.4 kJ/mol at 25 °C).

Nitrogen required as balancing item to account for the production of ammonia is derived from:

1. data for the production of nitrogen(fixed)-ammonia (e.g. from USGS 2006);

2. the amount of nitrogen required to produce one tonne of ammonia, which is about 0.83 tonnes N for 1 tonne NH<sub>3</sub> (assuming conventional reforming in modern ammonia plants – UNEP/UNIDO 1998);

by multiplying ammonia production in t (1) with nitrogen requirements per ton (2).

### Specific issues related to balancing items input side (and in total)

**Combustion of energy carriers in the context of emission-relevant consumption:** The emission-relevant consumption of energy carriers includes both energetic (combustion) and non-energetic processes. Emissions from combustion of energy carriers are usually by far dominating. Significant non-energetic emissions may, however, come from the production of blast furnace steel where the carbon stemming from coke in pig iron production is blown out as CO<sub>2</sub> through injection of technical oxygen. For a more comprehensive economy-wide MFA, this amount of oxygen for the process related emissions of CO<sub>2</sub> from coke should also be accounted for.

Advanced compilers of MFA may set up at first an account for the emission relevant consumption of energy carriers by type, and then account for oxygen as balancing item on the material input side. Respective energy consumption data are found in common energy statistics or energy balances.

**Table 31: Oxygen content of energy carriers (in % of weight)**

	Oxygen content in % (wt/wt)
Sewage gas/ Biogas/ Landfill gas	14.93
Hard coal	4.94
Coke (hard coal)	1.70
Hard coal briquettes	2.78
Brown coal, crude	6.00
Dust- and dry coal	16.78
Hard brown coal	12.73
Brown coal briquettes and -coke	16.78
Mine gas	14.93
Coke oven gas	14.93
Natural gas, Crude oil gas	0.19
Other solid fuels	35.97
Blast furnace gas	34.35

Source: derived from Frischknecht et al. 1994, Kugeler et al. 1990, Osteroth, 1989.

**Intrinsic CO<sub>2</sub> in materials:** Process-related CO<sub>2</sub> emissions from intrinsic CO<sub>2</sub>-contents of materials refer to cement and lime production:  $\text{CaCO}_3 + \text{heat} \rightarrow \text{CaO} + \text{CO}_2$ . These emissions are reported in NAMEAs and in the CRF. It has to be assured that the resulting CO<sub>2</sub> is definitely excluded from the CO<sub>2</sub> value used for O<sub>2</sub> calculation.

**Intrinsic oxygen content of energy carriers:** Some energy carriers contain oxygen. For an advanced balancing approach this intrinsic oxygen content of energy carriers has to be determined and subtracted from the oxygen calculated as balancing item for combustion, in order to derive the (real) net demand for O<sub>2</sub> for combustion. Exemplary values for oxygen in energy carriers are shown in table 31.

**Nitrogen for combustion as balancing item - input side:** Emissions of nitrogen oxides (NO, NO<sub>2</sub>) from fuel combustion in motors result at least partly from inputs of nitrogen in ambient air. This nitrogen input can in principle be calculated using standard coefficients based on emissions of NO<sub>2</sub>.

## **Balancing items: Output side (gases)**

### **Introduction**

Balancing items on the output side of the account are meant to equalise discrepancies resulting from data for material inputs. The main processes concerned are combustion of fuels and respiration of humans and livestock.

### **Data sources**

Data sources underlying the derivation of balancing items are:

for combustion: (1) data for the combustion of energy carriers to account for hydrogen contents of energy carriers resp. resulting emissions of water vapour, taken e.g. from energy balances (see also balancing items – input side) (2) similarly, data for the water contents of fuels for combustion.

auxiliary data needed to account for CO<sub>2</sub> and water vapour from respiration are population numbers and livestock numbers commonly found in general statistical sources and agricultural statistics (e.g. FAOSTAT), respectively.

## Data compilation

### E.2.1.1 Water vapour from moisture content of fuels

In the combustion process the moisture contained in fuels is emitted as water vapour (H<sub>2</sub>O). Resulting emissions can be estimated based on average values for water emitted per tonne energy carrier combusted:

**Table 32: Water vapour from moisture content of fuels**

energy carrier	water vapour in t per t energy carrier
Hard coal	0.02
Coke (hard coal)	0.02
Hard coal briquettes	0.02
Brown coal, crude	0.59
Dust- and dry coal	0.11
Hard brown coal	0.18
Brown coal briquettes and -coke	0.12
Fuel oil, light	0.001
Fuel oil, medium and heavy	0.005
Other solid fuels	0.16

Source: derived from Frischknecht et al. 1994, Kugeler et al. 1990, Osteroth, 1989

### E.2.1.2 Water vapour from the oxidised hydrogen components of fuels

As with the carbon component also the hydrogen component of fossil energy carriers is oxidised during combustion. The resulting water is released to the air as water vapour.

**Table 33: Water vapour from oxidised hydrogen component of fossil energy carriers**

energy carrier	water vapour in t per t energy carrier
Sewage gas/ Biogas/ Landfill gas	1.77
Hard coal	0.42
Coke (hard coal)	0.07
Hard coal briquettes	0.37
Brown coal, crude	0.17
Dust- and dry coal	0.37
Hard brown coal	0.36
Brown coal briquettes and -coke	0.37
Mine gas	1.77
Coke oven gas	1.77
Natural gas, Crude oil gas	2.05
Gasoline	1.28
Diesel	1.19
Aviation gasoline	1.34
Fuel oil, light	1.21
Fuel oil, medium and heavy	1.05
Liquid gas	1.59
Refinery gas	1.92
Other solid fuels	0.45
Blast furnace gas	0.02

Source: derived from Frischknecht et al. 1994, Kugeler et al. 1990, Osteroth, 1989

### E.2.2 Gases from respiration of humans and livestock

CO<sub>2</sub> and water vapour (H<sub>2</sub>O) from respiration can be calculated using standard coefficients based on population numbers and livestock numbers (see table 34).

**Table 34: Metabolic CO<sub>2</sub> and H<sub>2</sub>O production of humans and livestock**

	t CO <sub>2</sub> per capita resp. head and per year	t H <sub>2</sub> O per capita resp. head and per year
Humans	0.30	0.35
Cattle	2.92	3.38
Sheep	0.24	0.27
Horses	2.19	2.53
Pigs	0.30	0.35
Poultry	0.01	0.01

Source: Wuppertal Institute data base, based on Matthews et al. 2000.

## Material flow indicators

Similar to national accounts, also in material flow accounting highly aggregated indicators can be derived from the detailed data sets normally comprising several hundred material categories. We distinguish between extensive and intensive indicators.

### Extensive indicators

Definition: In general a property which varies directly with the size of the system is called an **extensive** property (e.g. volume, mass, or energy).

**Direct Material Input (DMI)** measures the direct input of materials for use into the economy, i.e. all materials which are of economic value and are used in production and consumption activities, except balancing items. DMI equals domestic extraction (used) plus imports. DMI is not additive across countries. For example, for EU totals of DMI the intra-EU foreign trade flows must be subtracted from the DMIs of Member States

**Domestic material consumption (DMC)** equals domestic extraction plus imports minus exports. DMC measures the annual amount of raw materials extracted in a national economy, plus all physical imports minus all physical exports. It is important to note that the term “consumption” as used in DMC denotes “apparent consumption” and not “final consumption”. DMC is defined in the same way as other key physical indicators such as e.g. “total primary energy supply” - TPES. DMC represents the part of all material inputs into an economic system that remains there until released to the environment. DMC therefore signifies the “domestic waste potential” of an economy (Weisz et al. 2006).

**Physical trade balance (PTB)** equals physical imports minus physical exports. The physical trade balance, thus, is defined reverse to the monetary trade balance (which is exports minus imports), taking account of the fact that in economies money and goods move in opposite direction. A physical trade surplus indicates a net import of materials, whereas a physical trade deficit indicates a net export.

**Net Additions to Stock (NAS)** measures the ‘physical growth of the economy’ (assuming that the balance is in most cases positive), i.e. the quantity (weight) of new construction materials used in buildings and other infrastructure, and materials incorporated into new durable goods such as cars, industrial machinery, and household appliances. Materials are added to the economy’s stock each year (gross additions), and old materials are removed from stock as buildings are demolished, and durable goods disposed of (removals). These

decommissioned materials, if not recycled, are accounted for in DPO. The difference between gross additions and removals represents the net-additions to stock.

**Domestic processed output (DPO)** measures the total weight of materials which are released back to the environment after having been used in the domestic economy. These flows occur at the processing, manufacturing, use, and final disposal stages of the production-consumption chain. Included in DPO are emissions to air, industrial and household wastes deposited in controlled and uncontrolled landfills, material loads in wastewater and materials dispersed into the environment as a result of product use (dissipative flows). Recycled material flows in the economy (e.g. of metals, paper, glass) are considered flows within the socio-economic system not crossing the relevant system boundaries and thus not included in DPO.

### **Intensive indicators**

Definition: As distinguished from an extensive property an **intensive** property is one that is independent of the size of the system being considered (e.g. temperature, pressure or density). For cross-country comparisons, intensive material flow indicators are used to compensate for the differences in size. As is common in environmental accounting, we here use population as denominator to compare the levels of economy-wide material use between nation states. In addition we propose the following intensive indicators:

To indicate overall material efficiency of an economy, we relate DMC to GDP. There are two types of efficiency indicators.

**Material intensity** is defined as the DMC to GDP ratio.

**Material productivity** is the inverse of material intensity, thus the GDP to DMC ratio.

**Area Intensity: DE or DMC to total land area ratio:** The ratio between material flows and total land area indicates the scale of the physical economy vis a vis its natural environment. We denote this indicator as area intensity.

**DE/DMC:** The ratio of domestic extraction to domestic material consumption indicates the dependence of the physical economy on domestic raw material supply. We therefore denote the DE to DMC ratio as “domestic resource dependency” (see Weisz et al. 2006).

**Import to DMI ratio and export to DMI ratio:** The ratios between imports and exports, respectively, to DMI indicate the import or export intensities of the physical economies. Together they can be addressed as “trade intensity” indicators. Sometimes also expressed as import or export per DMC

The use of different denominators is important for the analysis as different aspects of the physical economies become visible and comparable.

# References

## Literature

- Adriaanse, A., S. Bringezu, A. Hammond, Y. Moriguchi, E. Rodenburg, D. Rogich, and H. Schütz. (1997): *Resource Flows: The Material Basis of Industrial Economies*. World Resources Institute, Washington, D.C.
- Ayres, R. U. and U. E. Simonis. (1994): *Industrial Metabolism: Restructuring for Sustainable Development*. United Nations University Press, Tokyo, New York, Paris.
- Ayres, R. U. and Ayres, L. W., and Masini, A. (2006): An application of exergy accounting to five basic metal industries. In: von Gleich, Arnim et al. (Eds.): *Sustainable metals management. Securing our future-steps towards a closed loop economy*. Dordrecht: Springer, Eco-Efficiency in Industry and Science Bd. 6, pp. 141-194.
- Barbiero, G., S. Camponeschi, A. Femia, G. Greca, A. Macrì, A. Tudini, and M. Vannozzi. (2003): *1980-1998 Material-Input-Based Indicators Time Series and 1997 Material Balance of the Italian Economy*. ISTAT, Rome.
- Biology-Online.Org. (2005): *Seeds*. Available at <http://www.biology-online.org/dictionary/Seeds>. Retrieved 03/07/07.
- BMVEL. (2001): *Statistisches Jahrbuch über Ernährung, Landwirtschaft und Forsten der Bundesrepublik Deutschland*. Landwirtschaftsverlag, Münster-Hiltrup.
- Böhm, E., T. Hillenbrand, F. Marscheider-Weidemann, C. Schempp, S. Fuchs, and U. Scherer (2000): *Bilanzierung des Eintrags prioritärer Schwermetalle in Gewässer*. UBA-FB 000181, Federal Environmental Agency, Berlin.
- Bringezu, S. and H. Schütz (2001): *Material use indicators for the European Union, 1980-1997: Economy-wide material flow accounts and balances and derived indicators of resource use*. Eurostat Working Paper 2/2001/B/2, 29 June 2001.
- Buchgraber, K., A. Deutsch, and G. Gindl. 1994. *Zeitgemässe Grünland-Bewirtschaftung*. Stocker Verlag, Graz, Stuttgart.
- Cembureau, 1998. World Statistical Review. World Cement Market in Figures 1913/1995. The European Cement Association, Brussels.
- Cembureau, 2013. World Statistical Review. World Cement Market in Figures. The European Cement Association, Brussels.
- Commission of the European Communities (2005): Thematic strategy on the sustainable use of natural resources (TSURE). Brussels: Commission of the European Communities (CEC), COM (2005) 670 final <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52005DC0670:EN:NOT>
- Council of the European Union (2006): Review of the EU Sustainable Development Strategy (EU SDS) - Renewed Strategy. Brussels: Council of the European Union, DG I, 10117/06.
- CSIRO (2010). CSIRO and UNEP Asia-Pacific Material Flows online database: <http://www.cse.csiro.au/forms/form-mf-start.aspx>. See also Schandl, H. and J. West. 2010. Resource use and resource efficiency in the Asia-Pacific region. *Global Environmental Change* 20(4): 636–647.
- EC (2002): Regulation (EC) No 2150/2002 of the European Parliament and of the Council of 25 November 2002 on waste statistics (Text with EEA relevance). *Official Journal of the European Communities* L 332, 1-36. Available at
- EEA (2005): *Annual European Community CLRTAP emission inventory 1990–2003: Submission to the Executive Body of the UNECE CLRTAP*. EEA Technical Report No 6/2005.

- EEA (2006): *European Community greenhouse gas inventory 1990–2004 and inventory report 2006: Submission to the UNFCCC Secretariat*. EEA Technical Report No 6/2006.
- ESA (1995): *European System of National and Regional Accounts (ESA 95)*. Commission of the European Communities (Council Regulation of 25 June 1996), <http://circa.europa.eu/irc/dsis/nfaccount/info/data/ESA95/en/titelen.htm>
- European Parliament and Council (2002): *Sixth Community Environment Action Programme*, Decision 1600/2002/EC. Brussels: Official Journal of the European Communities, L242/1-15.
- Eurostat (2001): *Economy-wide Material Flow Accounts and Derived Indicators: A methodological guide*. Office for Official Publications of the European Communities, Luxembourg.
- Eurostat (2002): *Material use in the European Union 1980-2000. Indicators and Analysis*. Luxembourg: Eurostat, Office for Official Publications of the European Communities, prepared by Weisz, H., Fischer-Kowalski, M., Amann, C., Eisenmenger, N., Hubacek, K., and Krausmann, F.
- Eurostat (2005): *Waste generated and treated in Europe – Data 1995-2003*. Office for Official Publications of the European Communities, Luxembourg.
- Eurostat (2006): *Statistics on the trading of goods - User guide*. Office for Official Publications of the European Communities, Luxembourg.
- Eurostat (2007). *Economy-wide Material Flow Accounting. A Compilation Guide*. European Statistical Office, Luxembourg.
- European Statistical Office, Luxembourg. Eurostat (2009a): *Manual for Air Emissions Accounts* (draft v2.2, 23 February 2009, revisions included after TF discussions), Luxembourg.
- Eurostat (2009b): *Sustainable Development Indicators. Sustainable Production and Consumption*. <http://epp.eurostat.ec.europa.eu/portal/page/portal/sdi/indicators/theme2>.
- Eurostat, (2009c). *Economy wide Material Flow Accounts. Compilation Guidelines for reporting to the 2009 Eurostat questionnaire* (Version 01 - June 2009).
- Eurostat, (2012). *Economy-wide Material Flow Accounts (EW-MFA). Compilation Guide 2012*, Luxembourg.
- Eurostat, (2013). *Economy-wide Material Flow Accounts (EW-MFA). Compilation Guide 2013*, Luxembourg: [http://epp.eurostat.ec.europa.eu/portal/page/portal/environmental\\_accounts/documents/2013\\_EW-MFA\\_Guide\\_10Sep2013.pdf](http://epp.eurostat.ec.europa.eu/portal/page/portal/environmental_accounts/documents/2013_EW-MFA_Guide_10Sep2013.pdf)
- Fischer-Kowalski, M. (1998): *Society's Metabolism: The Intellectual History of Material Flow Analysis, Part I, 1860 – 1970*. In *Journal of Industrial Ecology* 2, 61-78.
- Fischer-Kowalski, M. and H. Weisz (2005): *Society as Hybrid Between Material and Symbolic Realms: Toward a Theoretical Framework of Society-Nature Interrelation*. In: Redclift, M. R. and G. Woodgate (eds.). *New Developments in Environmental Sociology*. Edward Elgar, Cheltenham and Northampton, 113–149.
- Fischer-Kowalski, M., Krausmann, F., Giljum, S., Lutter, S., Mayer, A., Bringezu, S., Moriguchi, Y., Schütz, H., Schandl, H., Weisz, H., 2011. *Methodology and indicators of economy wide material flow accounting. State of the art and reliability across sources*. *Journal of Industrial Ecology*, 15 (6), 855-876.
- Frischknecht, R., Hofstetter, P., Knoepfel, I. (1994): *Environmental life-cycle inventories of energy systems: methods and selected results*. Swiss Federal Institute of Technology (ETH), Zürich. Switzerland.
- Gonzales de Molina and Victor Toledo. 2014. *The Social Metabolism - A Socio-Ecological Theory of Historical Change*. Vol. 3. Environmental History. New York, Heidelberg: Springer.

- GVM - Gesellschaft für Verpackungsmarktforschung mbH (2005): Importe und Exporte von gefüllten Verpackungen. Wiesbaden, unpublished: Studie im Auftrag des Statistischen Bundesamtes
- Herrero, M., P. Havlík, H. Valin, A. Notenbaert, M.C. Rufino, P.K. Thornton, M. Blümmel, F. Weiss, D. Grace, and M. Obersteiner. (2013). Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. *Proceedings of the National Academy of Sciences*: 201308149.
- Hohenecker, J. (1981): Entwicklungstendenzen bei der Futtermittellieferung Österreichs, dargestellt am Beispiel ausgewählter Jahre. *Die Bodenkultur. Austrian Journal of Agricultural Research* 32, 163-187.
- IEA (2014): Energy Statistics and balances of OECD and Non-OECD Countries. International Energy Agency. URL: <http://www.iea.org/>
- IPCC (2000): *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. Available at <http://www.ipcc-nggip.iges.or.jp/public/gp/english/>. Retrieved 03/06/07.
- IPCC (2006): *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Japan: IGES
- IPCC (2007): *Climate Change 2007. Mitigation. Contribution of working group III to the Fourth Assessment report of the IPCC*. Cambridge UK and New York, USA: Cambridge University Press
- Klinnert (1993): *Erfassung von statistischem Datenmaterial über mineralische Rohstoffe*. Report to the Material Flows and Structural Change Division of the Wuppertal Institute. Unpublished.
- Krausmann, F., Erb, K.-H., Gingrich, S., Haberl, H., Bondeau, A., Gaube, V., Lauk, C., Plutzer, C., Searchinger, T., (2013). Global human appropriation of net primary production doubled in the 20th century. *Proceedings of the National Academy of Sciences of the United States of America*, 110, 10324-10329.
- Krausmann, F., K.-H. Erb, S. Gingrich, C. Lauk, and H. Haberl. 2008. Global patterns of socioeconomic biomass flows in the year 2000: A comprehensive assessment of supply, consumption and constraints. *Ecological Economics* 65(3): 471–487
- Krausmann, F., Gingrich, S., Eisenmenger, N., Erb, K.-H., Haberl, H., Fischer-Kowalski, M., (2009). Growth in global materials use, GDP and population during the 20th century. *Ecological Economics*, 68 (10), 2696-2705.
- Kugeler, K., Phlippen, P.-W. (1990): *Energietechnik - Technische, ökonomische und ökologische Grundlagen*, Springer-Verlag Berlin, Heidelberg, New York.
- Leffland, K. and H. Kærsgaard (1997): *Comparing Environmental Impact Data on Cleaner Technologies (CEIDOCT)*. EEA, COWI, Copenhagen. Available at <http://reports.eea.europa.eu/TEC01/en/tech01.pdf>. Retrieved 03/06/07.
- Matthews, E., C. Amann, S. Bringezu, M. Fischer-Kowalski, W. Hüttler, R. Kleijn, Y. Moriguchi, C. Ottke, E. Rodenburg, D. Rogich, H. Schandl, H. Schütz, E. van der Voet, and H. Weisz (2000): *The weight of nations: Material outflows from industrial economies*. World Resources Institute, Washington, D. C.
- Meissner, R. (1994): Wohin mit der Gülle?. In: GSF (ed.), *Mensch und Umwelt: Wasser*, Vol. 9, pp. 55-60.
- Ministry of the Environment, Government of Japan (1992): *Quality of the Environment in Japan 1992*. Available at <http://www.env.go.jp/en/wpaper/1992/index.html>. Retrieved 03/06/07.
- Muukkonen, J (2000): *TMR, DMI and Material Balances, Finland 1980-1997*. Statistics Finland, Eurostat Working Papers 2/2000/B/1. Office for Official Publications of the European Communities, Luxembourg.
- OECD (2006): *International Trade by Commodity Statistics - Standard Definitions*. Available at <http://www.oecd.org/dataoecd/60/63/1947767.htm>. Retrieved 03/06/07.

- OECD/IEA/Eurostat (2005): *Energy statistics manual*. IEA, Paris.
- Osteroth, D. (1989): Von der Kohle zur Biomasse. Chemierohstoffe und Energieträger im Wandel der Zeit. Springer-Verlag Berlin, Heidelberg, New York.
- PCA (2007): Cement and Concrete Basics. Available at [http://www.cement.org/basics/concretebasics\\_concretebasics.asp](http://www.cement.org/basics/concretebasics_concretebasics.asp). Retrieved 03/07/07.
- Penman, J., M. Gytarsky, T. Hiraishi, T. Krug, D. Kruger, R. Pipatti, L. Buendia, K. Miwa, T. Ngara, K. Tanabe, and F. Wagner (2003): *Good Practice Guidance for Land Use, Land-Use Change and Forestry*. IPCC National Greenhouse Gas Inventories Programme, IGES-IPCC, Hayama.
- REN21 (2005): *Renewables 2005 Global Status Report*. Worldwatch Institute, Washington, D.C.
- Scasny, M., J. Kovanda, and T. Hak (2003): Material flow account, balances and derived indicators for the Czech Republic during the 1990s: results and recommendations for methodological improvements. In *Ecological Economics* 45, 41– 57.
- Schaffartzik, A., Mayer, A., Gingrich, S., Eisenmenger, N., Loy, C., Krausmann, F., 2014. The global metabolic transition: Regional patterns and trends of global material flows, 1950–2010. *Global Environmental Change* 26, 87–97.
- Schaffartzik, A., Eisenmenger, N., Krausmann, F., Weisz, H., 2014a. Consumption-based Material Flow Accounting. *Journal of Industrial Ecology* 18, 102–112.
- Schandl, H., West, J., 2010. Resource use and resource efficiency in the Asia-Pacific region. *Global Environmental Change* 20, 636–647.
- Schütz, H. and S. Bringezu (1993): Major Material Flows in Germany. In *Fresenius Environmental Bulletin* 2, 443-448.
- Smith, B.E. (2002): Nitrogenase Reveals Its Inner Secrets. In *Science* 297, 1654-1655.
- Steger, S., Fekkak, M., Erren, M., Lischka, S., Bringezu, S., Scharp, M. (2009): MaRes AP 2.3. Öffentliche Infrastrukturen. Arbeitsbericht zu Phase II „Bestimmung der aktuellen Bestandsgrößen und des Materialspeichers der Referenzsysteme“. Wuppertal.
- Steurer, A. (1992): *Stoffstrombilanz Österreich 1988*. Social Ecology Working Paper,, IFF Social Ecology, Vienna.
- Stiller, H. (1996): Materialintensitätsanalysen von Transporten – Neue Prioritäten für Instrumente? (in German with an English Summary). In J. Köhn and M.J. Welfens (eds.). *Neue Ansätze in der Umweltökonomie*. Metropolis-Verlag, Marburg, 253-284.
- Tagiguchi, H., Takemoto, K., 2008. Japanese 3R Policies Based on Material Flow Analysis. *Journal of Industrial Ecology* 12, 792–798.
- Ulbricht, M. (2006): Stoffströme im Tiefbau. Quantifizierung des Ressourcenverbrauches der deutschen Straßeninfrastruktur. Studienarbeit in der Abteilung Sicherheitstechnik der Bergischen Universität Wuppertal, durchgeführt am Wuppertal Institut. Unveröffentlicht.
- UNEP-UNIDO (1998): Mineral Fertiliser Production and the Environment, Part 1: The Fertilizer Industry's Manufacturing Processes and Environmental Issues. Technical Report No. 26.
- United Nations (2004): International Merchandise Trade Statistics. Compilers Manual. Department of Economic and Social Affairs, Statistics Division, United Nations, New York.
- UNSD 2008. United Nations Energy Statistics Database. United Nations Statistics Division, New York.
- USGS (2006): Nitrogen (Fixed) – Ammonia Statistics. Available at <http://minerals.usgs.gov/ds/2005/140/nitrogen.pdf>. Retrieved 03/07/07.
- WCO. 2006. Harmonised System News. Available at [http://www.wcoomd.org/ie/En/Topics\\_Issues/topics\\_issues.html](http://www.wcoomd.org/ie/En/Topics_Issues/topics_issues.html). Retrieved 03/06/07.

- Weisz, H., F. Krausmann, C. Amann, N. Eisenmenger, K. Erb, K. Hubacek, and M. Fischer-Kowalski. (2006): The physical economy of the European Union: Cross-country comparison and determinants of material consumption. In *Ecological Economics* 58 (4), 676-698.
- Weisz, Helga, Amann, Christof, Eisenmenger, Nina, Krausmann, Fridolin, and Hubacek, Klaus (2004): Economy-wide Material Flow Accounts and Indicators of Resource Use for the EU: 1970-2001. Final report to Eurostat, contract no. Estat/B1/Contract Nr. 200241200002. Wien: IFF Social Ecology
- Wheeler, R.O., G.L. Cramer, K.B. Young, and E. Ospina (1981): *The World Livestock Product, Feedstuff, and Food Grain System: An Analysis and Evaluation of System Interactions Throughout the World, With Projections to 1985*. Winrock International, Morrilton.
- Wiedmann, T.O., Schandl, H., Lenzen, M., Moran, D., Suh, S., West, J., Kanemoto, K., 2013. The material footprint of nations. PNAS 201220362. doi:10.1073/pnas.1220362110
- Wirsenius, S. (2000): Human Use of Land and Organic Materials. Modeling the Turnover of Biomass in the Global Food System. *Doktorsavhandlingar vid Chalmers Tekniska Högskola* 1574, 1-255.
- Wirsenius, S. (2003). Efficiencies and biomass appropriation of food commodities on global and regional levels. *Agricultural Systems* 77(3): 219–255.
- Wood, R., Stadler, K., Bulavskaya, T., Lutter, S., Giljum, S., de Koning, A., Kuenen, J., Schütz, H., Acosta-Fernández, J., Usubiaga, A., Simas, M., Ivanova, O., Weinzettel, J., Schmidt, J.H., Merciai, S., Tukker, A., 2014. Global Sustainability Accounting—Developing EXIOBASE for Multi-Regional Footprint Analysis. *Sustainability* 7, 138–163.

## Databases and Statistical Sources

- BGR – Federal Institute for Geosciences and Natural Resources. Bundesrepublik Deutschland: Rohstoffsituation (Annual Report in German). Schweizerbart'sche Verlagsbuchhandlung, Stuttgart.
- BGS - British Geological Survey. European Mineral Statistics / World Mineral Statistics (Published Annually). Available at [http://www.bgs.ac.uk/mineralsuk/free\\_downloads/home.html#EMS](http://www.bgs.ac.uk/mineralsuk/free_downloads/home.html#EMS)
- CLRTAP - Convention on Long-Range Transboundary Air Pollution. For inventories compiled under this convention, please refer to EEA 2005.
- Comext – Eurostat's Statistics on the Foreign Trade of the EU Member States. Available at <http://comext.eurostat.ec.eu.int>
- Comtrade – UN Commodity Trade Statistics Database. Available at <http://comtrade.un.org/>
- DG TREN (2008): EU energy and transport in figures. Statistical Pocketbook 2007/2008. Luxembourg: Office for Official Publications of the European Communities, 2008
- ETC - European Topic Centre on Resource and Waste Management.  
International Databases available at [http://waste.eionet.europa.eu/wastebase/international\\_databases](http://waste.eionet.europa.eu/wastebase/international_databases)  
National Databases available at [http://waste.eionet.europa.eu/wastebase/national\\_databases](http://waste.eionet.europa.eu/wastebase/national_databases)
- FAOSTAT – Statistical Databases of the Food and Agriculture Organisation of the United Nations. Available at <http://faostat.fao.org/>
- FISHSTAT – FAO Fishery Statistics Programme. Available at [http://www.fao.org/figis/servlet/static?xml=FIDI\\_STAT\\_org.xml&dom=org&xp\\_nav=3,1,1](http://www.fao.org/figis/servlet/static?xml=FIDI_STAT_org.xml&dom=org&xp_nav=3,1,1)
- IEA - Energy Statistics of the International Energy Agency. Available at <http://www.iea.org/Textbase/stats/index.asp>
- Energy Statistics of OECD Countries (CD-ROM, 2006 Edition), see [http://www.iea.org/Textbase/publications/free\\_new\\_Desc.asp?PUBS\\_ID=1075](http://www.iea.org/Textbase/publications/free_new_Desc.asp?PUBS_ID=1075)
- PAN – Pesticide Action Network Pesticides Database. Available at [http://www.pesticideinfo.org/List\\_ChemicalsAlpha.jsp](http://www.pesticideinfo.org/List_ChemicalsAlpha.jsp)
- PRODCOM – Eurostat's Statistics on the Production of Manufactured Goods. Available at [http://epp.eurostat.ec.europa.eu/portal/page?\\_pageid=2594,58778937&\\_dad=portal&\\_schema=PORTAL](http://epp.eurostat.ec.europa.eu/portal/page?_pageid=2594,58778937&_dad=portal&_schema=PORTAL)
- SIMETRIC - Standard to Metric Conversion Factor Tables: Mass and Density of Materials. Available at [http://www.simetric.co.uk/si\\_materials.htm](http://www.simetric.co.uk/si_materials.htm)
- USGS - U.S. Geological Survey International Mineral Statistics and Information. Available at <http://minerals.usgs.gov/minerals/pubs/country/>
- United Nations Industrial Commodity Production Statistics Dataset. Available at <http://unstats.un.org/unsd/industry/default>

# List of abbreviations

## Acronyms

AOX	Adsorbable Organic Halogens
BGR	Federal Institute for Geosciences and Natural Resources, Germany
BGS	British Geological Survey
BMVEL	Federal Ministry of Consumer Protection, Food and Agriculture, Germany
BOD	Biological (Biochemical) Oxygen Demand, <i>cf. Glossary</i>
CEIDDOCT	Comparing Environmental Impact Data on Cleaner Technologies
CLRTAP	Convention on Long-Range Transboundary Air Pollution (UNECE)
CN	Combined Nomenclature
COD	Chemical Oxygen Demand, <i>cf. Glossary</i>
COWI	International Consultancy within Engineering, Environmental Science & Economics
CPA	Classification of Products by Activity
COMEXT	Eurostat (↓) Foreign Trade Database
COMTRADE	UN Commodity Trade Statistics Database
CRF	Common Reporting Format (for UNFCCC (↓) - related reporting), <i>cf. Glossary</i>
DDT	Dichloro-Diphenyl-Trichloroethane, a pesticide and POP (↓)
DE	Domestic Extraction, <i>cf. Glossary</i>
DPO	Domestic Processed Output, <i>cf. Glossary</i>
DM	Dry Matter
DMC	Domestic Material Consumption, <i>cf. Glossary</i>
DMI	Direct Material Input, <i>cf. Glossary</i>
EC	European Community
EEA	European Environmental Agency
ESA	European Systems of Accounts 1995 (ESA 95)
ETC-WMF	European Topic Centre on Waste and Material Flows
EU	European Union
Eurostat	Statistical Office of the European Communities
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	FAO Statistical Database
FISHSTAT	FAO Fishery Statistics
FW	Fresh Weight
GCV	Gross Calorific Value
GDP	Gross Domestic Product
GHG	Greenhouse Gas, <i>cf. Glossary</i>
GNP	Gross National Product

GVA	Gross Value Added
GWP	Global Warming Potential, <i>cf. Glossary</i>
HFCs	Hydrofluorocarbons (group of greenhouse gases)
HM	Heavy Metals
HS	Harmonised Commodity Description and Coding System
IEA	International Energy Agency
IGES	Institute for Global Environmental Strategies
IPCC	Intergovernmental Panel on Climate Change
ISIC	International Standard Industrial Classification of all Economic Activities
ISTAT	National Institute of Statistics, Italy
LPG	Liquid Petroleum Gas
LULUCF	Land Use, Land Use Change, and Forestry
mc	moisture content
MFA	Material Flow Analysis, <i>cf. Glossary</i>
MFAcc	Material Flow Account, <i>cf. Glossary</i>
MI	Material Intensity, <i>cf. Glossary</i>
NAMEA	National Accounting Matrices Including Environmental Accounts, <i>cf. Glossary</i>
NMVOC	Non-Methane Volatile Organic Compound
NACE	Classification of Economic Activities Within the European Communities
NAS	Net Additions to Stock, <i>cf. Glossary</i>
NGL	Natural Gas Liquids
NIR	National Inventory Report (to the UNFCCC (↓)), <i>cf. Glossary</i>
NMS	(EU) New Member States, <i>cf. Glossary</i>
OECD	Organisation for Economic Co-operation and Development
PAH	Polycyclic Aromatic Hydrocarbons
PAN	Pesticide Action Network
PBT	Persistent, Bioaccumulative, and Toxic Pollutant
PCA	Portland Cement Association
PFCs	Perfluorocarbons (group of greenhouse gases)
PM	Particulate Matter
PM10	Particulate Matter with a diameter less or equal to 10 micrometers
POP	Persistent Organic Pollutant
PRODCOM	Products of the European Community (database)
PTB	Physical Trade Balance, <i>cf. Glossary</i>
REN21	Renewable Energy Policy Network for the 21 <sup>st</sup> Century
RME	Raw Material Equivalent, <i>cf. Glossary</i>
ROM	Run-Of-Mine, <i>cf. Glossary</i>
SEEA	System of Integrated Environmental and Economic Accounting 2003 (United Nations)
SITC	Standard International Trade Classification
SNA	System of National Accounts, <i>cf. Glossary</i>

TBT	Tributyltin, a toxic additive found in paints
TOMP	Toxic Organic Micro-Pollutant
TPES	Total Primary Energy Supply, <i>cf. Glossary</i>
UN	United Nations
UNECE	UN Economic Commission for Europe
UNEP	UN Nations Environment Programme
UNEP GC	UNEP Governing Council
UNFCCC	UN Framework Convention on Climate Change
UNIDO	UN Industrial Development Organisation
USGS	United States Geological Survey
WCO (OMD)	World Customs Organisation

## Units

cap	capita
J	joule(s)
scm	solid cubic meter
t, mt	tonne(s), metric tonnes (1 t = 1000 kg)
toe	tonnes of oil equivalent
MJ	Megajoule

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